THE COMING AGE OF ROCKET POWER

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BY
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THE COMING AGE OF ROCKET POWER

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FIRST EDITION

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THIS BOOK IS DEDICATED

with gratitude and affection to my friends and colleagues in rocketry; to John Shesta, James Wyld, Laurence Manning, Lovell Lawrence, Jr., H. F. Pierce, Samuel Lichenstein, Cedric Giles, Roy Healy, Alfred Africano and all the others who were persistent pioneers in the development of rocket power; to Lee Gregory, my wife, who withstood the trials and dangers of early experimentation with the rest of us, and through whose continuing interest my own enthusiasm has been sustained; to the members of the American Rocket Society who gave us support, encouragement and some of the funds for experimentation and publication; to all the known and unknown friends of rocketry everywhere; the experimenters, engineers, mathematicians, idea-suppliers, mechanics and workers who are now engaged in bringing about the Coming Age of Rocket Power.

Acknowledgments

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Especially am I indebted to Messrs. Shesta, Wyld and Giles for careful reading of the manuscript, and their useful comments and suggestions. The table of jet velocities and the table of heats of combustion in Chapter II are the work of Mr. Shesta, the jet velocity calculations having been made especially for this book. Messrs. Shesta and Wyld devoted many hours of valuable time to rechecking the computations throughout the book, and Mr. Wyld in addition provided the stimulating comments on "micro-instrumentation" which close Chapter XIII.

For help with the illustration of the book I am especially indebted to Jacques Martial and Robert Scull, of the firm of Martial and Scull, industrial designers. Their work combines imagination and artistry with accuracy of mechanical detail to a remarkable degree. Through his interest in the subject Mr. Martial particularly is today one of the foremost industrial designers and artists in this field.

G. EDWARD PENDRAY

New York, December 1, 1944

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THE COMING AGE OF ROCKET POWER

Chapter I

"... An Equal and Contrary Reaction"

1.

In the early dawn a dark object, spitting fire from its tail and emitting a curious throbbing roar, comes darting across the English countryside toward London. The antiaircraft guns begin to bark. Blobs of flak smoke appear around the speeding craft. Still it roars ahead, a brainless, pilotless, aerial burden of death, blind yet curiously knowing, persistent, purposeful—and filled with portent of a day to come.

Thousands of miles away, an airplane attacks a submarine. Before the undersea craft can get its machinery in motion for a dive, two rockets are ejected from the plane like spears of vengeance. They strike the conning tower of the sub; one shears into the metal and explodes. The other detonates above the deck and spatters hot steel over everything. The submarine falters in its dive; more rockets arrive, and by the time the fighting plane zooms overhead to finish the job, there is little left to do. Rocket power has got there first.

Another place, and at another time, a fast airplane takes off without the aid of propellers, and with a roar plunges into the sky, by jet propulsion. At a celebration, skyrockets stream upward, leaving trails of colored fire. Along a stormy coast a small ship is wrecked and foundering; its passengers in peril. A rocket suddenly flies outward from the shore, carrying a thin line—and scores of lives are saved.

These diverse phenomena at first glance seem entirely unrelated, yet they have one important thing in common. All are manifestations of rocket power. To anyone who reads the newspapers, it has become amply evident in recent months that jet propulsion, rockets and rocket power are hereafter to have their

effect on the life of every person in the world, in peace and in war, whether he has any interest in the technical aspects of the subject or not. Jet propulsion is clearly to be a new force in the world; something we must all be willing to know about and understand.

This book is the story of rocket power; what it is, how it works, how it comes to be and what it promises for the future. So far as I know, it is the first attempt in any language to show the relation of the various kinds of rocket power now at work, and provide a simple explanation for the new kind of engine which rocket power represents. In it, unless you are already an old hand at rocket talk, you will meet some new and possibly bizarre characters. You will, for example, meet the Third Law of Motion, a statement of the principle on which the rocket motor operates. You will come to be familiar with jet velocity. You will find out how under proper circumstances explosives may act as fuels, and how a rocket motor can push without requiring anything to push against.

You will acquire a new vocabulary, too; the language[1] of the coming age of rocket power. You will learn to speak familiarly of combustion chambers, gyro-pilots, trajectories and regenerative motors. You will meet the "jato," the "chase-me-Charlie," the "swish" and "loxygen." When you have finished, I hope you will in some measure be moved and inspired by the new thing that is coming into the world, for good or ill: the thing which, in all its manifestations, I have chosen to call by its simplest and most obvious name, *rocket power.*

2.

Jet propulsion is rocket power. Thermal-jet engines, duct engines, jet motors, jet-propelled planes, robot bombs, jet-propelled gliders, war rockets, thrusters and skyrockets—all of these are merely different aspects of rocket power. All of them, as we shall see, operate on exactly the same basic principle: the principle of a motor that *thrusts* or pushes, instead of producing rotary motion in a shaft or wheel.

This is the one simple difference that makes rocket power

[1] In the Appendix of this book is a glossary of new terms for the age of rocket power.

unique—and incidentally makes it so difficult at first for our wheel-conditioned minds to grasp. A few thousand years ago some person, now unknown and long forgotten, invented the wheel. It was such a successful device, so easily adapted to doing its share of the world's work, that when fuel-burning engines were first developed they naturally were made to be harnessed to it. The reciprocating motion of their pistons was transformed by means of a crank into a rotary movement for only one purpose: to turn wheels. Even when we set the engine to the task of moving us through the air, we did so through the medium of a kind of wheel, the propeller.

To understand the principle of jet propulsion, we must think therefore in terms of an engine that does not turn a wheel; a new kind of engine, working on a totally new principle; differing from all the other engines of the world; an engine that *thrusts.*

Such an engine is known as a reaction motor, and reaction motors of all kinds, whether rocket motors, jet engines or duct engines, produce their thrust by a unique method. They simply jet out a stream of gas or other material at high velocity. The resulting reaction is what provides the push. That is why, of course, the principle of the reaction motor is known as *jet propulsion.*

The first apparatus ever proposed to make use of jet propulsion was described by Heron, or Hero, a philosopher of old Alexandria, about the beginning of the Christian Era. Heron was an ingenious man who also invented a slot machine and a fire engine. In one of his books, the *Pneumatica*, he outlined plans for building a little device called the "aeolipile." It consisted of a hollow sphere mounted on pivots, equipped with two opposed bent metal spouts. Steam under pressure was introduced into the sphere through a pipe in one of the supports. The vapor, spurting from the curved spouts, caused the sphere to spin rapidly.

A similar demonstration of rudimentary rocket power is to be seen in the ordinary kind of rotating lawn sprinkler. The streams of water, jetting from the sprinkler nozzles, produce reaction against the nozzle arms to make the sprinkler spin.

Some sea creatures, especially the squid, have been using jet propulsion for hundreds of millions of years. The squid fills his mantle cavity with water, then squirts it out with a powerful convulsive motion of his muscles. The water-jet drives him for-

ward; the movement being proportional to the speed and volume of the water thrust out behind.

3.

The skyrocket, which aside from Heron's toylike contrivance was the first artificial device to make use of jet propulsion, was invented more than seven hundred years ago. But neither Heron nor the hundreds of generations of fireworks makers, nor presumably the squid, had any real understanding of the principle of jet propulsion. They only knew it worked.

It remained for Sir Isaac Newton, some 265 years ago, to give us the basis for understanding what rocket power really is, and the unique things it can do. Newton, formulating in simple language the three Laws of Motion his mathematics and observation had helped him to discover, wrote out in Latin this observation: "To every action there is always an equal and contrary reaction; the mutual actions of any two bodies are always equal and oppositely directed."

Thus, the hand that pushes a cradle is itself pushed *by* the cradle, to exactly the same degree and in the opposite direction. The foot that thrusts downward on the earth is *thrust upward* by the earth in precisely the same amount. The bullet that is ejected by a gun causes the gun to recoil—and the two actions are not only opposite in direction, but are equal in amount.

This is the statement of Newton's Third Law of Motion. Although it describes a phenomenon we daily experience throughout our lives, few people consider or even recognize the reaction that necessarily is a part of every movement of every object. It is important that we recognize it now, for the Third Law is a complete statement of the principle upon which the reaction motor operates.

In most human activities the *action* is what is wanted; the reaction is thrown away or ignored. In jet propulsion, the "action" is thrown away. The *reaction* is the particular harvest we are seeking.

4.

The simplest form of reaction motor—and the best known—is the one that drives an ordinary skyrocket.

Here is a cross-section drawing of a skyrocket. At the tip is a cone-shaped cap which provides rudimentary streamlining to aid the rapid upward flight of the projectile. Immediately under the cap usually are nested the combustible pellets, the "stars" that cascade brilliantly into the sky at the top of the flight. These are the payload of the skyrocket; they are not a basic part of the rocket itself.

Into the main body of the rocket, usually contained in a heavy paper tube, a quantity of black powder is packed. This is the fuel or *propellant* charge, (*A*). The material is usually a form of ordinary gunpowder, often mixed with extra charcoal or some other material to slow down the rate of combustion. It is squeezed into the rocket under high pressure, thus packed tightly into a solid cake. Because it is solid, the flame cannot permeate the cake, so combustion takes place only at the exposed surface of the cone-shaped *blast chamber*, (*B*).

The simple thrust mechanism—or *motor*—of the rocket is completed by constricting the walls of the case below the blast chamber to form a nozzle. Sometimes the throat of the nozzle is reinforced with clay or other hard material to prevent its burning out. A fuse (*D*) and a long stick—a crude balancing device—complete the rocket.

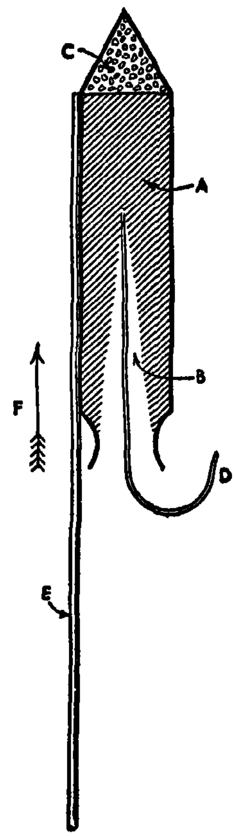


FIG. 1. Cross section of a skyrocket.

On firing, what happens is this:

Heat from the fuse ignites the surface of the powder on the walls of the cone-shaped blast chamber. The powder does not explode, but a continuous combustion takes place very rapidly, releasing large quantities of gas at high temperature. Considerable pressure builds up instantly in the chamber, since the hot gas is formed at a much faster rate than it can easily escape through the restriction at the nozzle. The net effect is to eject a stream of gas at great velocity, directed backward. This thrusts the rocket forcibly in the opposite direction.

As the fuel burns, the blast chamber rapidly enlarges, but the restriction at the nozzle continues to keep the pressure high and

guides the escaping jet. The rocket takes off with a tremendous swish, emitting a stream of sparks and fire, and flies until the fuel is completely consumed. Then an arrangement at the top of the tube fires the "stars" and the bursting charge in which they are packed.

In a jet motor such as that of the skyrocket there are no moving parts—except the stream of escaping gas. It is by no means easy to grasp just how this jet with nothing to push against, exerts the surprising power that thrusts the whole body of the rocket so violently toward the sky.

The common notion is that the jet does its work by pushing against the air. Superficially this seems reasonable. The air is certainly a resisting medium. But a stream of gas, no matter how rapidly it is moving, or how dense it may be, is no solid connecting rod, capable of pushing against something and transmitting the push back against whatever is adjacent to its starting end. Gas consists of billions upon billions of tiny hard pellets—the molecules of which it is composed. These are not connected together in any way. On the contrary, they are seeking to escape from each other as fast as possible, expanding like a cloud of steam.

The surrounding air similarly consists of random, flying molecules. When a molecule of ejected gas strikes a molecule of air, the collision sends both off in other directions and with altered speeds. But how could such a collision, even when multiplied by the thousands of billions, drive a rocket which is not in any way connected to them? Drive it, moreover, in a specific direction?

The answer, of course, is that they couldn't. The air in no way helps to drive the rocket. It only impedes the action—by getting in the way of the projectile in front, and hindering the rapid, straight-line ejection of the gas behind.

It is something else that drives the rocket—and this brings us back to Newton and his Law of Motion: "To every action there is always an equal and contrary reaction; the mutual actions of any two bodies are always equal and oppositely directed."

Consider the ejected gas as one "body"; the rocket as the other.

The rocket, forcing the gas to escape, pushes it violently toward the earth. The gas, escaping, pushes the rocket as violently toward the sky.

This is jet propulsion, or rocket power, the simple principle of the reaction motor.

5.

It may still not be entirely clear exactly how this mysterious reaction occurs. Here is another drawing that may help in the further understanding of it.

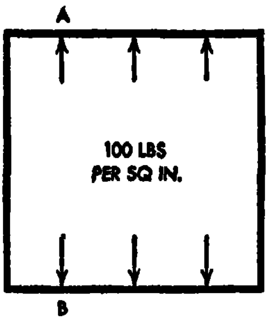


FIG. 2.

Imagine a hollow box, filled with gas under pressure. For convenience, let us say the pressure is 100 pounds per square inch. This means, of course, that every square inch on the inside of the box will be pushed upon by gas with a steady pressure of 100 pounds. Under these conditions the box itself will not move in any direction, for the total pressure on each side will exactly balance the total pressure on the opposite side.

Now, suppose a hole were to be cut in side *B*, exactly (for convenience in doing our mental arithmetic) one square inch in area. At once we have a new condition in the box, as shown in the second diagram. Note that the pressure exerted by the gas on side *B* is now no longer exactly equal to that on side *A*. It is, in fact 100 pounds less. The box will therefore be pushed in the direction of the arrow *E*, with a force of 100 pounds. The push will continue as long as we bring in fresh supplies of gas or fuel to keep the pressure in the box at the established level.

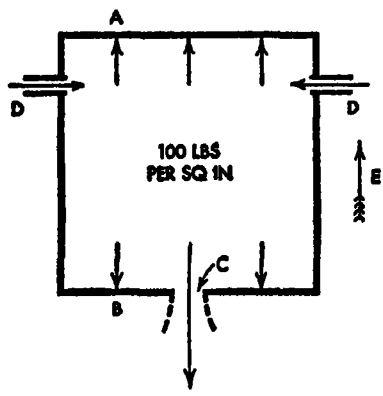


FIG. 3.

In essentials, this is how things go in the reaction motor. An important refinement is the addition of a nozzle at *C*, to direct the escaping gas and control its expansion. This facilitates the movement of the stream and adds to the thrust, often as much as 35 to 50 per cent or more.

The approximate thrust or push of any reaction motor may be calculated by multiplying the area of the orifice of the throat (*C*) by the pressure of the gas in the chamber, and adding about 50 per cent for the additional contribution of the nozzle. The exact value of the thrust will, of course, vary according to several factors, including the fuel used, the pressure of the gas, completeness of combustion and an experimentally determined item rocket engineers call "the constant of the nozzle," which depends upon the nozzle size, shape and other factors.[2]

6.

Now, just a few more words of technical talk, and we are through with this phase of our examination of the fundamentals of rocket power.

To the engineer, the reaction motor is a *heat engine*, just as are steam, gasoline and the ordinary kinds of engines. The purpose of a heat engine is to extract the heat (chemical energy) of appropriate fuel and turn it into some sort of motion (mechanical power) which can be made to do work.

There is no known way in which a heat engine can transform *all* of the chemical energy of its fuel into useful mechanical energy. There are invariably some losses in the transfer. Most heat engines, in fact, are furiously wasteful; a natural concomitant of the various stages through which the power must pass on its way from fuel to crankshaft.

The ordinary steam locomotive transforms only 8 to 10 per cent of the energy of the coal it burns into forward motion of the train, and hence in engineering terms it is said to be only 8 to 10 per cent efficient. For every 100 shovelfuls of coal the firemen puts into the firebox, fewer than ten do any useful work.

The automobile engine is somewhat more efficient than the locomotive. It is able to deliver, in the form of forward movement of the car, some 20 to 25 per cent of the energy contained in the gasoline it uses.

The reciprocating airplane engine has been brought to an

[2] The thrust can also be calculated, of course, by applying the formula $T=MV$, where T is thrust, M is the mass ejected per second, and V is the velocity of the jet in feet per second.

extreme state of refinement, and besides, it burns better fuels. So it is not surprising that it does better than its cousin, the automobile engine. It is still far from perfectly efficient. Even the best and largest airplane engines obtain less than 35 per cent of their fuel's energy in the form of shaft horsepower. Out of every 100 gallons of high-octane gasoline the aviator loads into his tanks, more than 65 will be unavoidably wasted through the heat losses of his engine.

What efficiency, considering that it has few or no moving parts to waste motion and dissipate energy, may we expect of the reaction motor?

The answer is that the thermal efficiency, measured in terms of the speed of the jet, may theoretically go as high as 85 per cent, though in motors of the types now available it does not usually exceed 40 to 50 per cent. This is twice as good as an automobile engine and considerably better than the best airplane engine. To convert all, or most, of this jet power into driving power, however, the motor *must be traveling at or near the speed of its jet.*

Now this velocity requirement, which applies to all jet-driven devices of any kind whatever, is of singular importance. For it follows that the reaction motor is a heat engine that is efficient only at high speeds, and one that is ill-adapted for slow travel.

The jet velocities of the several types of reaction motors now developed vary from about 1,200 feet a second up to a theoretical 17,000 feet a second or more. The smaller of these figures—the minimum speed at which a jet-driven projectile or aircraft could travel with full efficiency—is about 800 miles an hour, or a little over the speed of sound.

The upper figure, which represents a future possibility in the matter of jet velocities, is about 11,000 miles an hour, or more than six times as fast as an artillery shell!

The reaction motor clearly does not offer any mere alternative way of making fuels do the world's work. It is no simple substitute or stand-in for the gasoline engine. Instead, it opens the way to an entire new world of velocities, altitudes and powers which have hitherto been closed to us; and consequently to a whole new world of human experiences and possibilities.

In the age of rocket power we shall become accustomed to enormous concentrations of power in small engines; we shall reach great altitudes, and we shall move at velocities almost beyond our present imagining. Not only are these the possibilities of rocket power; they are also its requirements.

Chapter II

The Hunger of the Beast

1.

In SHAKESPEARE's *Julius Caesar*, the Roman Cassius inquires: "Now in the name of all the gods at once, upon what meat doth this our Caesar feed, that he is grown so great?"

When talk goes around of a motor that can travel faster than an artillery shell, operate in a vacuum, deliver more energy than a reciprocating engine and do it with few or no moving parts, the question sooner or later arises: "Just what kind of fuel must such a motor burn?"

It is to be expected that something very unusual indeed will be required. Atomic energy, possibly, or obscure and costly chemical mixtures. One of the most common notions about rocket power is that the fuel question is a principal obstacle; that somehow or other a basically new fuel or fuel combination must be utilized to make the reaction motor do practical work.

Nothing is farther from the truth. Reaction motors need no special fuels. Their demands are by no means as severe as those of the ordinary gasoline engine, to say nothing of the airplane engine, which requires highly refined high-octane gasoline to function at all.

Some types of reaction motors will work perfectly well on ordinary, cheap and easily obtainable fuels; on kerosene, gasoline, alcohol, fuel oil; on gunpowder, powdered metals, coal dust dissolved in oil—and for that matter, on ordinary coke or coal, if a suitable method can be developed for feeding them into the blast chamber.

Some fuels, of course, are better than others, both for convenience and the energy they will yield. But it can be safely set down that the fuels required by the age of rocket power are ready at hand. No new invention is needed in this field to open

the gates; the reaction motor is as easily satisfied in the way of fuel as is the steam engine.

2.

A fuel is obviously something from which a motor can extract energy. Since by the laws of nature the total amount of energy in a system remains constant, the fuel can yield up only the amount of energy that is in it, and no more. The energy of most fuels is locked in the molecules of the compound in a form known as chemical energy, and was placed there during the process of forming the chemical.

The energy of coal, for example, comes from the sun. Coal is the fossilized residue of the trees and vegetation of the Carboniferous age of the earth, when what are now coal fields were lush swamps, abounding in vegetation. With the energy they absorbed from the sun, plants took carbon dioxide and moisture from the air, and together with chemicals from the soil, formed it into the materials of their stalks and leaves and trunks. Upon reaching maturity, the vegetation died, fell into the swamp, gave way to succeeding generations of vegetation which grew up, absorbed sun energy in the same way, grew old and passed along.

In the course of ages, enormous thickness of decaying vegetation accumulated in these swamps, formed principally of carbon compounds made with the aid of the energy of the sun. As time went on, the deposits were covered over with earth and rock, were compressed, underwent numerous chemical changes, but preserved their essential carboniferous character. The energy absorbed from the sun by these ancient plants and trees remained locked in the coal, in the form of chemical energy. When coal is burned today, in a very real sense it is the power of the sunlight that fell upon the earth 500 million years ago that is being released in the form of heat.

The power in petroleum is similarly derived from the sun, through ancient vegetation. The energy in petroleum products, such as gasoline or kerosene, is solar energy. An automobile runs by sun power, even though the sunlight that propels it actually fell upon the earth before the first mammals appeared, when plant life and sea life were virtually the only forms of living things on the globe.

Indirectly or directly, all energy on the earth, except that ob-

tained from radioactive materials, came originally from the sun. It is our only basic source of power, whether for the forming of vegetation, the raising of water to fill rivers, the raising of the winds or direct heat. But we are able through chemistry to form compounds which do not exist normally in nature, and which also contain large amounts of energy. Nitroglycerine, for example, is an energy-containing compound formed by reacting nitric acid with glycerine. Both of these substances, in turn, required the use of energy in their production, and the amount of energy that nitroglycerine will release, upon detonation, is only that contributed to the compound by the original nitric acid and glycerine.

Broadly, there are two basic types of chemical reactions, so far as energy is concerned. These are known as the *exothermic*, or heat-releasing reactions, and the *endothermic*, or heat-absorbing reactions. Endothermic reactions cannot take place except in the presence of heat, which they can absorb in the process of forming new molecular arrangements. Such compounds are likely to be unstable, and will usually yield readily to further reactions which enable them to release heat or energy. Thus endothermic reactions store up chemical energy in compounds, whereas exothermic reactions give up the energy again.

If water, for example, is subjected to great heat under proper conditions (or direct electric current, another form of energy) it can be dissociated into its original elements, oxygen and hydrogen. The separation will absorb a great deal of energy, and the process of separation is, therefore, an endothermic reaction.

Subsequently, if the two gases resulting from the separation are mixed and caused to combine chemically—which they will do with explosive violence—water is again formed, plus a great deal of heat. The amount of heat produced by the exothermic reaction forming water will be exactly equal to the heat-energy required to separate the same amount of water into its constituent elements, hydrogen and oxygen.

Now, reaction fuel is a substance containing chemical energy, which it can be caused to release at exactly the right time, place and rate to produce the jet that makes a reaction motor work. Gasoline, kerosene, alcohol and the like are all compounds that contain large quantities of chemical energy, but clearly they do

not, of themselves, give it up. Something else is needed at just the proper time to produce the exothermic reaction.

That substance is oxygen.

3.

Oxygen, of course, is what makes fuel give up its energy in steam or gasoline engines, too. About one-fifth of the earth's atmosphere is oxygen, and it is this atmospheric oxygen that is used in fireboxes to make coal burn under boilers. It is likewise drawn into the carburetors of gasoline engines, and there mixed with gasoline vapor to produce the explosive mixture triggered off in the cylinder by the electric spark. It is the principal reason for the breathing of men and animals. Living creatures are heat engines, too, requiring oxygen to burn the fuels that supply energy for their activities.

The oxygen required by the reaction motor may come directly from the air, as in the case of the airstream engines (see Chapter IV), or it may be supplied in liquid, chemical or gaseous form as one of the propellants of a true rocket motor.

It is mainly the way the oxygen is obtained that distinguishes the various types of reaction motors from each other. In every type, the combustion must take place with great rapidity. If atmospheric oxygen is used, an enormous quantity of air is required. It can be supplied by large air compressors, but in this case there must be a source of power within the reaction motor to operate the air compressor. This naturally adds to the complexity of the motor, and to its weight and size.

In the simple "chemical fuel" or true rocket types of reaction motors, oxygen is supplied in various ways: (1) the oxygen can be put into chemical compounds that will readily give it up again at the proper time and place, (2) it can be put directly into the molecules of the fuel itself, in such a way that, at the proper signal, the necessary chemical changes will take place to release the energy. Or (3) atmospheric oxygen can be separated from the other gases of the air, compressed and liquefied, and fed into the reaction motor in its most highly concentrated form, either as liquid oxygen pure and simple or possibly in the form of ozone.

The fuel that drives skyrockets, as we have noted, is basically gunpowder. This fuel is a mixture of three substances: charcoal,

sulphur and saltpeter. Charcoal is a spongy form of carbon, offering a large surface area which facilitates its reaction with oxygen. Sulphur likewise readily reacts with oxygen. Saltpeter, known chemically as potassium nitrate, is a compound containing oxygen. In gunpowder, these substances are intimately mixed together. When heat is applied, as by a match or fuse, the potassium nitrate gives up oxygen. This reacts with the near-by sulphur and charcoal, producing intense heat. The chain of reactions thus started spreads rapidly through the mixture. As it does so, the energy locked in its materials is released in the form of heat.

It is important to note that the products of this series of reactions, at the temperature of the reaction, are principally gases. The carbon yields carbon dioxide, the gas which under other circumstances puts the bubbles in soda water. The sulphur produces sulphur dioxide. Both are produced in large volume, at high temperature.

In the simple gunpowder-fuel reaction motor, it is the carbon dioxide and sulphur dioxide which form the principal materials of the jet. The heat produced by the chemical reaction appears in the form of jet velocity. The more heat, other things being equal, the higher the jet speed—and hence the greater the thrust developed by the motor.

A great many oxygen-yielding chemicals other than saltpeter are known which might serve under proper circumstances as oxidizers for rocket fuels. One of the most interesting is hydrogen peroxide.

As used for bleaching or as a disinfectant, hydrogen peroxide is usually diluted with water to such an extent that the mixture may contain only a tenth or less peroxide. The pure hydrogen peroxide is a clear liquid, about 50 per cent heavier than water. Each molecule contains two atoms of hydrogen and two atoms of oxygen. Since the oxygen weighs nearly sixteen times as much as the hydrogen, by weight hydrogen peroxide is almost all oxygen. If it could be made to give this oxygen up readily, it would be nearly as good as pure oxygen itself and easier to handle. Unfortunately only one of its two oxygen atoms is easy to drive out of the molecules. Even so, nearly half the weight of the original hydrogen peroxide can be converted into available oxygen.

Another oxidizer that has received much attention from experimenters is nitric acid, a compound of nitrogen, hydrogen and oxygen. In each molecule are one atom of nitrogen, one of hydrogen and three of oxygen. By weight, therefore, the oxygen comprises nearly four-fifths, but the acid will readily give up less than half of it. This means that three-fifths or more of the weight of nitric acid is inert material which cannot take part in the chemical reaction with the fuel.

Of these two compounds, hydrogen peroxide would seem to be the better bet, since nearly half of its weight is available oxygen, whereas only about two-fifths of the weight of nitric acid can be converted into useful oxygen. But pure hydrogen peroxide is tricky stuff. It has a nasty habit of detonating all by itself at unexpected moments, and must be carefully handled to prevent a premature and disastrous release of its oxygen and energy.[1]

Nitric acid, on the other hand, is reasonably stable. In its "fuming" form, it contains in solution another oxygen-yielding compound, nitrogen peroxide, which adds a little to the available oxygen. The difficulty with nitric acid is its general unpleasantness. It readily attacks metals, clothing, experimenters. Its other values, however, are so good that it has been used with promising results in many kinds of reaction motor applications.

4.

Compared with these powerful oxidizers, the saltpeter used in gunpowder may sound like pretty feeble stuff. Nevertheless, potassium nitrate is a little better than half oxygen by weight. At red heat it gives up a third of its oxygen. At higher temperatures, such as are present in the explosion of gunpowder, it may dissociate still further.

As an oxidizer, therefore, it is not so bad—and may be nearly as good as nitric acid, except, of course, that it is a solid, and therefore cannot be used in any except dry-fuel motors.

[1] Nevertheless, the Germans used it—or some form of it—in much of their wartime rocket work, notably in some of the reaction motors used to launch their famous robot bombs toward London in 1944, in their V-2 rockets, and also, reportedly, in their rocket-driven fighter airplane, the ME-163.

There are many compounds and mixtures besides gunpowder, of course, that contain oxygen, and will steadily give up their energy by reorganization.[2] Many of them are unusable as jet fuels, however, because of the furious rate at which the reaction takes place. Most of them belong to the class of explosives known as detonators. They yield up heat so fast they produce, instead of an orderly release of gas at high temperature and pressure, a shattering shock wave which destroys the apparatus in which they are contained.

It is usually not even necessary to confine a detonator to produce a shattering effect. Nitroglycerine (and also dynamite, which is nitroglycerine absorbed in inert matter, such as clay, to make it safer) will shatter a flat surface upon which it is lying. The explosive wave may travel through such compounds as fast as a mile a second, and far from producing a controllable stream of gas for a motor jet, such "fuels" would simply spatter the motor itself all over the surrounding countryside.

There are some exceptions. One is smokeless powder, which is made by plasticizing guncotton with a solvent, usually acetone, and forming it into strips or cords. In this form the combustion takes place somewhat more slowly, and at a regular rate. Smokeless powders also sometimes include mixtures of other substances, called "delayers," to slow the rate of burning, reduce the erosive effect of the products of combustion and otherwise improve them as propellants.

Another type of explosive that can readily be used as a reaction motor fuel is cordite, a blend of guncotton and nitroglycerine, mixed with stabilizing agents such as soft paraffin or petroleum jelly. There are many forms of cordite and smokeless powder, and within a reasonable degree they can be compounded to have definite characteristics that make them useful as rocket fuels. Most military rockets are powered with propellants of the cordite variety.

5.

The specifications for an ideal fuel are easy to draw up, but extremely hard to fill. What we are looking for is (1) a sub-

[2] If such a fuel is a liquid, it is known as a "monopropellant," that is, consisting of only one substance. When two separate substances must be used, such as liquid oxygen and gasoline, the combination is called a "dipropellant."

stance that contains the greatest possible amount of energy, with (2) the smallest possible weight and volume; that (3) will yield gas at high temperature and pressure steadily and with safety, and (4) which presents no special difficulties in handling.

There are no fuels that fulfill all of these specifications perfectly. We must search for some that come as near as possible. We find them, not among such explosives and detonators as we have been discussing, but much closer to home, among more familiar compounds.

For it turns out, providing we use some form of pure oxygen or an oxygen-rich chemical as our oxidizer, the best energy producers are those high in carbon and hydrogen. In short, right back where we started: gasoline, kerosene, benzol, alcohol, and other members of the hydrocarbon and alcohol families.

John Shesta, chief engineer of Reaction Motors, Incorporated, and one of the foremost of American rocket engineers, made a study of various possible fuels several years ago for the American Rocket Society, and constructed a table of available fuels, together with their total energy content as measured in British thermal units. The table, as published in *Astronautics*, the society's journal, in March, 1936, is as follows:

Heats of Combustion of Various Fuels by Weight

Substance		B.T.U. per pound	Lbs. Ox. required	Lbs. total weight	B.T.U. per lb. total weight
Hydrogen	H_2	51,900	8.00	9.00	5,760
Acetylene	C_2H_2	20,700	3.08	4.08	5,060
Ethylene	C_2H_4	20,000	3.43	4.43	4,520
Benzol	C_6H_6	17,300	3.08	4.08	4,330
Methane	CH_4	21,400	4.00	5.00	4,280
Ethane	C_2H_6	20,200	3.73	4.73	4,260
Pentane	C_5H_{12}	19,300	3.56	4.56	4,240
Hexane	C_6H_{14}	19,200	3.54	4.54	4,230
Heptane	C_7H_{16}	19,100	3.52	4.52	4,220
Dodecane	$C_{12}H_{26}$	18,700	3.48	4.48	4,170
Ethyl Alc.	C_2H_5OH	12,100	2.44	3.44	3,520
Methyl Alc.	CH_3OH	9,100	2.00	3.00	3,030
Smokeless powder		1,870	0.00	1.00	1,870
Black powder		1,000	0.00	1.00	1,000

If the names of some of these fuels seem strange, it is only necessary to remember that methane, ethane, heptane, and dodecane are members of the hydrocarbon series, derived from petro-

leum. Most motor fuels are mixtures of several of the pure hydrocarbon compounds, and vary a bit in the energy they contain, depending on the nature of the mixture. For practical purpose, it is sufficiently accurate to consider gasoline as equivalent to either heptane or hexane, and kerosene as equivalent to dodecane.

This table of comparative energies shows that liquid fuels of this type are far and away better than either black or smokeless powder, and that liquid hydrogen is the most powerful of them all. Liquid hydrogen, though, is rather impractical. It cannot be obtained commercially—though it could probably be manufactured if a suitable market were to develop for it. A more serious objection is that it boils at any temperature above -423 degrees Fahrenheit. This is so cold it approaches the temperature of absolute zero. Liquid hydrogen would therefore not only be expensive to manufacture; it would also be most difficult to store in its liquid state for any length of time. It would at all times be boiling furiously, and at any ordinary temperature would rapidly evaporate into gaseous hydrogen and be lost.

Liquid hydrogen also is very bulky, since it weighs only 7 per cent as much as water. In a rocket, this would increase the structure weight and tank weight, for huge vessels would be required to contain a given amount of it.

Of great theoretical value, however, would be the special form of hydrogen known as *monatomic* hydrogen. In ordinary gaseous hydrogen, the atoms cling together in pairs. They can be separated by passing a stream of the gas through an electrical discharge. After passing through the electrical arc, the single atoms will again unite, giving out enormous quantities of heat. If some way could be found to liquefy hydrogen in its monatomic state, and preserve its monatomic nature until it could be burned in a rocket motor, there would be a tremendous gain over ordinary liquefied hydrogen. The conversion from monatomic hydrogen to ordinary hydrogen (H_2) alone would produce some 90,000 B.T.U. of heat-energy per pound, corresponding to a theoretical jet velocity of 67,000 feet per second.

Unfortunately, nobody knows how to manufacture liquid monatomic hydrogen just yet, so we must perforce lay this idea on the shelf for the time being, and consider some of the practical, available fuels which may be used to drive the rocket motors of the present and immediate future.

Acetylene likewise rates excellently in the table, and it is obtainable in liquid form. But it is very unstable, and unless special precautions are taken, is a dangerous substance, decomposing violently under a variety of circumstances. Maybe research will find a way to keep it stable without adding too much weight to the tanks in which it must be carried. Until that time comes, we shall have to strike it, too, from our list of practical fuels.

Next on the list is ethylene, a gas sometimes used as an anesthetic. Closely following is benzol. Both of these substances are practical rocket fuels, and may loom large in the coming age of rocket power.

However, they are not enough better than gasoline to justify, at present, the inconvenience of obtaining them. Gasoline, available everywhere and at a reasonable cost, is nearly as good as benzol, and is much easier to handle. It is not surprising that much of the rocket experimenting of recent years has been done with liquid oxygen and gasoline, a good, simple, practical combination, and powerful enough, too, for all likely uses of rocket motors in the near future and for years to come.

This combination, it will be seen, is more than four times as powerful as gunpowder, more than twice as powerful as the best smokeless powder. It can produce an ejection speed, theoretically, of up to 14,500 feet a second—better than two and a half miles a second—and it is quite powerful enough to shoot a suitably designed projectile across the Atlantic Ocean, if a motor can be developed that utilizes a major part of the heat-energy it contains.

Here are the maximum theoretical jet velocities of a few typical or possible reaction motor fuels, as calculated by Mr. Shesta from their known total energy content:

Hydrogen and oxygen	17,000	feet	per	second
Acetylene and oxygen	15,900	"	"	"
Benzol and oxygen	14,700	"	"	"
Gasoline and oxygen	14,500	"	"	"
Kerosene and oxygen	14,400	"	"	"
Alcohol and oxygen	13,300	"	"	"
Smokeless powder	9,600	"	"	"
Black gunpowder	6,900	"	"	"
Gasoline and air	7,000	"	"	"

6.

Many other combinations of fuels and oxidizers have also been suggested, and experimenters have dealt with a number of them.

On account of the great heat evolved when powdered metals burn in oxygen—notably powdered magnesium and aluminum, these have often been suggested as possible rocket fuels. One difficulty is that the products of combustion are usually solids, and hence may merely foul the motor instead of producing a suitable jet. Another problem is getting the powdered metals into the motor at the proper rate and place. Several experimenters have tried mixing them with oil to form a paste, and forcing them into the motor in this state, Much more work will have to be done, however, before they can be considered practical fuels.

It has been suggested that powdered coal could be used as a reaction motor fuel by mixing it with fuel oil, and burning the combination with liquid oxygen. Some experimenters have also advanced the idea of using pure carbon in some finely divided state, as for example lampblack. Another idea is a motor which is itself made of carbon, and burns away with the fuel.

In 1934 Harry W. Bull, a rocket experimenter at Syracuse, New York, made one of the most elaborate series of tests on possible fuel substances ever reported.[3] He tried high-pressure steam; then a series of liquids with low boiling points, including carbon disulfide, alcohol, ether, carbon tetrachloride, methyl sulfide and chlorine. "After many explosions—I ceased experimenting along these lines," Mr. Bull reported in *Astronautics.*

He next tried a rocket motor using solidified carbon dioxide. He found it difficult to liberate the gas rapidly enough.

Next he experimented with a powder and paraffin mixture, intended to give a low exhaust temperature, but after several tests decided it was impractical.

He followed this with a motor burning magnesium metal: and next developed a powder rocket having the powder arranged in sections or tubes of small diameter to prevent too rapid burning.

Experiments then followed with these fuel combinations: nitroglycerine; alcohol and 30 per cent hydrogen peroxide; turpentine and nitric acid; gasoline and various nitrates.

[3] Mr. Bull had previously (about 1933) made a series of significant and important tests with liquid fuel motors using more conventional fuels, and had constructed one of the earliest regenerative liquid fuel motors.

Concluding his tests by developing a special monopropellant of his own (composition not revealed) which he called "Atalene," Mr. Bull tried more than seven hundred combinations of the liquid material. It was, as he described it, "cheap, colorless, leaves no residue on burning, can be stored for months, safe to handle and will not backfire." For ignition, however, it required to be heated to 400 degrees Fahrenheit, and this proved to be the stumper.

"Motors were designed especially to burn the new fuel," he reported to the American Rocket Society. "Five months were spent building new designs. . . . Many types of fuel heaters were tried before the final plan of spraying the fuel into a magnesium flame was perfected."

"Perfected" however was the wrong word. Shortly thereafter one of the experimental motors exploded violently, driving a jagged section of one-inch pipe into the experimenter's leg. Fortunately it left no permanent injury.

7.

Compared to the many experimental combinations we have been discussing, experimenters have come to think of liquid oxygen and gasoline as "safe" propellants. Accidents with these are by no means unknown, but the combination behaves itself remarkably well.

The real problem, in fact, is not the danger of explosion, but the difficulty of handling liquid oxygen. For this royal liquid is no quiet cooperator in the matter of producing rocket power. It has character all its own.

It is made by liquefying the air, then causing the other gases, principally nitrogen, to boil off and escape. The liquid occupies only about one eight-hundredth the space formerly occupied by the gas at ordinary atmospheric pressure. Pure liquid oxygen is a bluish, somewhat magnetic liquid. It is very cold, since it boils at −297 degrees Fahrenheit. At any temperature above this it evaporates at a furious rate.

An early rocket experimenter, explaining his difficulties with liquid oxygen, once wrote in a report to the American Rocket Society:[4]

[4] From "The History of the First A.I.S. Rocket," *Astronautics*, November-December, 1932.

At this point we learned one of the most serious difficulties with our rocket as an experimental apparatus. The opening into the oxygen tank was about half an inch in diameter. The tank itself was five feet long and one and a half inches in diameter, inside measure. To cool this long pipe sufficiently to hold a quart of liquid oxygen required the evaporation of nearly a quart of the liquid.

Even this would not have been of great consequence, were it not for the extreme difficulty of pouring the oxygen into the tank. Liquid oxygen, when poured on metal at ordinary temperatures, behaves somewhat like water spilled on a white-hot stove. It spatters and sputters, droplets of it bouncing about in the most unpredictable manner. When it comes to pouring such a liquid through a hole half an inch in diameter, even with the aid of a funnel, it requires sometimes as long as fifteen minutes to empty a quart, most of which either evaporates from the furiously boiling supply in the funnel, or spatters down the sleeves of the operator, inflicting innumerable tiny frostbites, like little scalded spots.

Moreover, the ingoing liquid is met by an upward rushing stream of oxygen gas, seeking to leave the tank. Several expedients were tried for introducing the oxygen, until we made a funnel with a long copper tube for a spout. This worked fairly well, but very slowly, and often became plugged with frost during the pouring operation. It required about three quarts of oxygen to get a full quart of the liquid into the tank.

This tale of difficulty was a common complaint of experimenters during the thirties, when rocket tanks and motors were small, and liquid oxygen, which was very expensive, had to be handled with extreme care. On one occasion a crowd which had gathered at Greenwood Lake, New York, to witness a liquid oxygen motor test was kept waiting more than four hours, in bitter cold weather, because the opening in the tank which had seemed more than adequate during construction, proved too small to permit any oxygen to enter. After much liquid had been wasted in the attempts to force some into the tank, the test had to be abandoned.

Liquid oxygen is not now such a problem, however. Experimenters have learned about its idiosyncrasies. They provide adequate openings through which to pour it. Moreover, they have

developed pressure methods of forcing it to go where wanted, whether it has a mind to do so or not.

Losses due to evaporation are not so easily overcome. Liquid oxygen can be kept a reasonable time in thermos-bottle-like containers known at Dewar flasks, which have spherical sheet-copper inner tanks, to hold the oxygen. Around these are one or more insulating tanks, separated from each other by evacuated spaces. Losses of oxygen from such containers in small sizes amount to about 10 per cent each twenty-four hours. In large tanks holding 20 or 30 gallons or more, losses over reasonable periods are negligible, but permanent storage of oxygen in any kind of tank is out of the question.[5]

When experimenters first began using it, liquid oxygen was rather rare and quite expensive. Experimenters paid as high as $1.50 to $2.00 a quart for it. In recent years production of both liquid air and liquid oxygen has increased enormously. Liquid oxygen is now delivered commercially by tank truck, and a gallon can be obtained for a fraction of what a quart once cost.

However, there is still the difficulty that it cannot be charged into the rocket motor at the factory and forgotten; it must be put into the tank of the rocket shortly before using. For this reason, military rockets, antiaircraft rockets, lifesaving rockets and such are regularly powered with dry fuels, usually either cordite in one of its many forms such as ballistite—or smokeless powder. Though these propellants have less energy than liquid oxygen and gasoline, they are more practical for such small projectiles, especially when they must be handled under a variety of field conditions, and often at times and places where filling with liquid oxygen would be quite out of the question.

8.

We see, then, that though much has yet to be learned about rocket fuels, there are already several practical combinations available which are quite suitable for ushering in the age of rocket power; fuels powerful enough for our immediate uses, easily obtainable, inexpensive, relatively safe and controllable.

They are hardly the ultimate, however. Research on rocket

[5] Some of the other liquid oxidizers, such as nitric acid, can of course be permanently stored.

fuels is going forward today at several experimental plants and rocket laboratories, and in at least three great universities. Out of this work there may come fuels that are more practical and advantageous than any so far conceived.

One may be the liquefied monatomic hydrogen, which we have already discussed. Another may be a practical, safe form of liquefied ozone, the trimolecular form of oxygen which theoretically would increase the jet velocity of either liquid hydrogen or gasoline by 1,500 feet per second over the velocity obtainable when burned with ordinary oxygen.

Chemical fuels of course will always have their limitations. The amount of releasable energy in any chemical combination is pitifully small when compared with the energy locked up within the atoms of its substance. The energy left as atomic power in the ashes of coal, for example, is a hundred thousand times greater than the chemical energy obtained from the coal when it is burned.

The trouble is: how can this energy be released in adequate quantities and in useful form? Before the war physicists had apparently come close to answering that question, and rocket experimenters naturally hoped that ultimately some form of atomic energy would make all chemical rocket fuels obsolete.

That time, however, is probably still far away, and the useful development of rocket power can hardly wait upon the unlocking of the secrets of the atom.

Gasoline and the hydrocarbons, or fuels of a similar nature, will have to do the job, and fortunately they are powerful, practical and convenient enough for any at present conceivable terrestrial use of rocket power.

Chapter III

Engines for a Day to Come

1.

So FAR as the basic principles are concerned, all jet-propulsion motors obey the same laws, and in that sense are identical. When it comes to practical application of these laws, it is soon seen that a bewildering number and variety of motors can be contrived, ranging all the way from low-powered water, steam or compressed-air jets to motors that produce a high-speed blast by burning gasoline, alcohol, benzol, hydrogen, or other fuels.

Moreover, there is at least one broad line of division among all the various types of reaction motors, according to the way in which oxygen is obtained for the combustion. If the oxygen is taken from the surrounding atmosphere, by compression of the air or other means, we have the class appropriately called the *airstream engines*. If the oxygen is supplied in the form of liquid oxygen or as some compound readily giving up oxygen, the motor belongs to the group which is designated as the *true rocket* or *chemical fuel motors*.

Each of these major groups is further subdivided. There are, for example, at least two basically different types of the true rocket motors, and at least three types, so far, of the airstream engines. Since we shall have frequent occasion to refer to these several types of motors and engines in this book, this table may prove a convenient point of reference:

TYPES AND CLASSES OF REACTION MOTORS

I. *The true rocket, or chemical fuel motors*:
   A. The dry-fuel rocket motor (burns solid fuels such as gunpowder or smokeless powder).
   B. The liquid-fuel motor (burns fuels such as liquid oxygen and gasoline, or liquid oxygen and alcohol).

II. *The airstream engines*:

A. The thermal jet engine (burns a variety of possible fuels, including gasoline and kerosene, with air delivered into the combustion chamber by means of a rotary compressor).

B. The intermittent duct engine (burns gasoline or similar fuels with air, compressed into the blast chamber by the ram effect. Action is pulsating or intermittent).

C. The continuous duct engine (burns the same fuels as the intermittent engine; also depends on atmospheric oxygen compressed by ram effect, but its action is continuous).

From this table we see that there is first of all the simple *dry-fuel rocket motor*, the kind that drives skyrockets and many types of military rockets such as the bazooka, the airplane rockets and the British "Z-gun" antiaircraft rocket.

Second, there is the *liquid-fuel rocket motor*, which provides power for many types of thrusters, catapults and some types of military rockets, also for such long-range rockets as the German "V-2" rocket weapon. Because of the energy in the fuels it can burn, the liquid-fuel motor is potentially the most powerful type of all. To liquid-fuel motors rocket engineers of the future will turn for power to send sounding rockets high into the atmosphere, to shoot mail and express over long distances, and to serve as auxiliary or even primary power for high-flying, superfast stratoliners of a coming age.

Among the airstream engines, the best known is the *thermal jet engine*, also called the "turbo-jet engine," the "turbo-jet" or the "swish." A thermal jet engine of somewhat primitive type was used by the Italians in their much-publicized demonstration flight by jet propulsion in 1940. A better version had already been developed by Captain Frank Whittle in England, and the Whittle version of the jet engine was brought to this country for manufacture in 1942.

The other types of airstream engines are *duct engines*, much simpler than the jet engine in that they require almost no moving parts, and get along without either air compressors or turbine wheels. They do, however, require that the aircraft or glider to which they are attached be given a rapid preliminary start. Duct engines, having no air compressor of their own, de-

pend at least partly on the compression or "ram effect" of the air during flight to provide them with oxygen to burn their fuels.

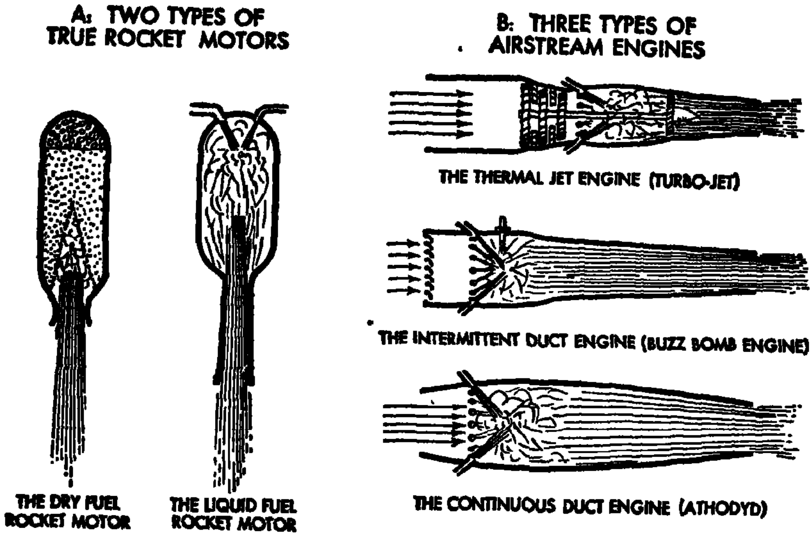


FIG. 4. Schematic representation of the five types of reaction motors.

The best known of the duct engines is the *intermittent duct engine*, one type of which—the "buzz-bomb engine"—was used by the Germans to propel their robot bombs in 1944 against London and southern England. It does not operate with a continuous blast, as does the thermal jet engine and the generally used types of rocket motors,[1] but proceeds by a series of pulses or intermittent explosions, hence the name.

Still under development is the *continuous duct engine*, sometimes called the *athodyd*, which may ultimately serve as auxiliary power for fast-flying aircraft. In principle it is similar to the intermittent type, depending on the ram effect of the air for compression, but at suitable high velocity it will produce a continuous blast of power.

2.

These, then, are the engines for the coming age of rocket power: the dry- and liquid-fuel rocket motors, the two kinds of

[1] It should be noted that the true rocket motors may also operate intermittently. An intermittent type of dry-fuel motor was developed by Dr. Robert H. Goddard as early as 1916.

duct engines, and the turbo-jet. Simplest of all, essentially, are the rocket motors, and it is to them we shall turn for the rest of this chapter, reserving discussion of the equally fascinating problems of the airstream engines for later treatment.

Historically, of course, the dry-fuel rocket motors were the earliest to appear. If we look once more at the skyrocket, the most familiar of the true rocket motors, we will perceive that the motor and the fuel supply are there most ingeniously combined. The fuel is made to provide its own motor, in the form of the cone-shaped blast cavity which rapidly enlarges as the fuel burns away.

This form of rocket motor offers no problems of metallurgy, because there is no metal. There is no problem about the burning out of the walls, for so long as they consist of fuel, burning is what is desired. This rocket motor obviously does very well the job it is designed to do. Unfortunately it does not provide us with a good pattern for rocket motors of more power and utility.

For one thing, the gas pressure is necessarily low, whereas good efficiency requires a relatively high pressure, measured in hundreds of pounds per square inch. Why is the pressure low? Because if it were higher, it would burst the paper tube in which the rocket is contained, or blow out the flimsy nozzle —or more likely still, cause the flame to permeate the powder charge, no matter how tightly packed. This might set the whole fuel supply off at once, resulting in an explosion instead of a flight.

Another problem with the skyrocket motor is that the combustion chamber changes shape and size continually throughout the run. At the beginning it is small. During the burning it rapidly enlarges. But since its enlargement depends both upon the rate and uniformity of the combustion of the fuel, the shape changes, too, along with the size. If for a given fuel, gas pressure, nozzle and other conditions there is only one best shape, the skyrocket can have it, at most, for only a fraction of a second. During the rest of its operation it is bound to be doing a less satisfactory job.

These problems of the skyrocket motor are shared by all forms of dry-fuel motors, though by ingenious methods some have been designed to overcome the worst difficulties.

The first considerable improvement was the application of a metal nozzle, properly shaped to give maximum aid to the escaping gases. Such a nozzle immediately improves the performance of the motor. Pressure can then be increased by substituting smokeless powder or cordite for the fuel, and exchanging metal or strong laminated plastic containers for the paper ones. This, however, may introduce a new problem: the new containers may weigh more than the paper, and if the chamber pressure is to be increased a great deal, we must be careful to see that the extra weight of the stronger jacket does not nullify the gain obtained from a more powerful fuel.

Dr. Robert H. Goddard, whose pioneer work established the modern period of rocket research, gave considerable study at one time to the problem of improving the performance of the dry-fuel motor. He discovered that the average velocity of ejection in an ordinary skyrocket was only about 1,000 feet a second, but when he fired charges of dense smokeless powder in strong steel chambers, with properly shaped smooth tapered nozzles, he obtained velocities of ejection up to nearly 8,000 feet per second. Assuming the masses ejected to be the same, the impulse of the later rocket motor would be eight times as great, with the same weight of fuel, and thus would theoretically drive a rocket not eight but sixty-four times as far—a very considerable reward for thus increasing the jet velocity.

However, it is not possible to add a steel jacket and metal nozzle without adding weight; so as a practical matter the skyrocket and the smokeless powder rocket could hardly start with weights, fuel charges and other factors even. The smokeless powder rocket would have to weigh more, or else carry less fuel or payload at the start.

To get around this it was early suggested by Dr. Goddard that the blast chamber should not be merely a cavity in the fuel supply, but a separate contrivance, into which the fuel could be inserted as needed. Several ingenious ways were suggested for doing this. Dr. Goddard's proposal was to shoot pellets of fuel into the chamber intermittently, like machine-gun bullets.[2] Simi-

[2] Dr. Goddard patented such an intermittent rocket apparatus in 1914, and brought it to a good state of development during the first World War. He later gave up this line of experiment, however, in favor of liquid-fuel motors.

lar ideas offered by other experimenters include thrusting a solid stick of fuel rapidly into the chamber through an orifice, the speed of insertion being equal to the rate of burning, or powdering the fuel and blowing it in by air or gas, through suitable inlet ports.

If one or another of these ideas were adopted, only the motor chamber (which could be relatively small) would need to be strong enough to withstand the high gas pressure of the blast; the fuel container could be light and flimsy, and thus add very little to the weight.

Unfortunately, any apparatus for shooting pellets into the chamber is likely to be heavy, expensive and cantankerous, full of personal little kinks and problems of its own. Blowing the powder into the chamber with gas pressure is no easy one to handle, either. Likewise, the idea of thrusting a stick of fuel into the chamber through some sort of opening runs into very special headaches, including the difficulty of sealing the edges of the orifice against back pressure without also making it too hard to push the fuel in. Too, there is the matter of judging to a high degree of accuracy just how fast the fuel will burn—solid fuels being particularly variable in this respect.

The upshot is that while the application of one or another of these ideas might possibly further improve the performance of dry-fuel rockets, experimenters and military experts have preferred to continue using dry-fuel rockets of the simpler sort—taking the disadvantages in exchange for the convenience and general freedom from worry that dry-fuel rockets without internal mechanism can have at the site of battle.

This should not be taken to mean that great advances have not been made, however. The demand for powerful, simple, dependable war rockets of many kinds has put great pressure on technical rocket men. The improvements have been almost countless, and include better metal and plastic jackets, proper metal nozzles—and above all, better fuels.

Practically all of the new fuels are related to cordite, of course. There are now not only many types of these propellants, but the charges are being made in a variety of ways, one of the most fascinating being extrusion. In this process the material is made in plastic form and pushed through dies—usually in factories operated by remote control—to produce long rods or

tubes of the fuel material of just the right size and shape to fit into the rocket bodies. These need only cutting to proper length and final insertion.

In most modern military rockets the fuel is burned with great rapidity. In the bazooka, for example, the whole charge goes off in a fraction of a second, while the rocket is traversing the length of the eight-foot launching tube.

The quick-burning effect is produced by a process just the reverse of that used in the skyrocket, where the powder is tightly packed to keep the flame from permeating it. In the quick-burning dry-fuel rocket, the charge is specially prepared to encourage the flame to get almost everywhere at once. If gunpowder or smokeless powder is used, the load may be in the form of "doughnuts" or pressed fuel, packed with loose powder to propagate the flame. If it is cordite or some other of the more powerful explosives, the charge may be fluted, hollowed or drilled full of holes, so the flame can eat it quickly, over a large surface.

The effect of this quick burning is to produce a takeoff almost like a cannon shot. The rocket gets away with a quick "ffff-tt." The flame is hardly more than a brilliant flash and then gone. The projectile flies almost all of the way to its target on momentum, obeying the same laws of ballistics as an artillery shell.

3.

For such short-range devices as military rockets, the dry-fuel motor does very well; in fact it is the only practical type. But this kind of motor will never give the power and sustained performance needed for high-altitude sounding rockets, for example, or long-range military or trajectory rockets. For these, we must turn to the liquid-fuel motor.

The dry-fuel rocket has obvious limitations which the liquid-fuel motor appears to overcome readily—but in so doing it introduces a host of new problems all its own.

To begin with, it is a device that functions only in the presence of intense heat. The temperature within a liquid-fuel rocket motor is almost always at or above the melting point of the materials of which it is constructed. Moreover, there is an enormous contrast in temperatures from one part of the motor to another.

At the point where the fuel enters, the thermometer may register as low as the boiling point of liquid oxygen, −297 degrees Fahrenheit. At the hottest point, the temperature may be at least half that of the surface of the sun.

The burden which these conditions put upon a simple, small and necessarily light structure is enormous. The surprising thing is that a liquid-fuel motor made of metals can operate at all. Yet motors have been developed in this country to give sustained performance for indefinite periods, to provide thrusts from a few pounds to 3,000 pounds or more[3] and weighing, for the largest sizes, not more than 50 to 75 pounds, or about ¼ ounce per pound of thrust. Smaller ones, capable of yielding thrusts up to 100 pounds, may be nested in the hand, and weigh less than a pound.

The high temperature at which the liquid-fuel motor must be operated to produce suitable results is no mere temporary obstacle which some ingenious trick or discovery may someday solve. Rather, it is inherent in the nature of fuels and jet velocities. It is the principal limiting factor on the operation of any jet motor.

To obtain a jet velocity of between 6,000 and 7,000 feet per second with fuels of the type in general use, the temperature inside the combustion chamber must be around 5,000 degrees Fahrenheit. To obtain a jet velocity of 8,000 feet per second, a blast-chamber temperature of about 8,000 degrees Fahrenheit is required. A jet velocity of 10,000 feet per second will need a temperature of 12,200 degrees, and a 12,000 foot-per-second jet can be generated only by operating at a temperature of some 17,300 degrees. No ordinary constructional metals, of course, will stand any of these temperatures, except for very brief periods. For that reason, the high jet velocities reported by experimenters, at least those above 7,000 feet per second, were obtained either for only a very short duration or under very special conditions that cannot readily be duplicated in practical rocket motors.

The melting point of aluminum, the most commonly used metal for rocket motors because of its lightness, is 1218 degrees

[3] The thrust developed by the German "V-2" rocket motor, which may have a life of only 60 to 70 seconds, is estimated at more than 26 tons.

Fahrenheit, or only about a fourth of the temperature required to produce a 6,000 to 7,000 foot-per-second jet. The melting point of steel, which is also used in motor construction is around 2,200 degrees; still well below the temperature of the 6,000 to 7,000 foot motor.

The most heat-resistant metal known is tungsten, which melts at about 6116 degrees Fahrenheit. It is a most difficult metal to work with, and so far apparently nobody has succeeded in making a practical rocket motor of it. Even if it were done, this metal by itself would be able to withstand the heat of a motor of only about 7,000 ft/sec velocity. It would melt before the velocity had been pushed up to 8,000 feet per second.

These figures, had they been produced by some skeptical mathematician before experiments with liquid-fuel motors began, might well have discouraged any attempts to make this kind of reaction motor work. The reality itself was quite discouraging at first even without benefit of such calculations.

Almost every rocket experimenter has seen motors of the finest steel burn out in less than a second of firing. At these temperatures it is not so much a matter of melting as of erosion. The metal behaves somewhat like an icicle in the flame of a blowtorch. The surface melts or softens. Then the furious blast of the escaping jet carries the softened part away, exposing new material underneath. Almost before the metal of the motor has become hot clear through, it has been cut to pieces by this process. Under such circumstances all ordinary ideas of cooling are futile.

Dr. Robert H. Goddard was the first experimenter on record to tackle the liquid-fuel motor problem, and was also the first to shoot a rocket powered by a liquid-fuel motor. The German experimenters of the *Verein für Raumschiffahrt* (German Rocket Society), however, were quicker than Goddard to report their experiences. Consequently, the history of their early attempts to harness liquid fuels is a well known and highly instructive tale.

Their first idea was to place the blast chamber of the motor directly in the liquid oxygen tank, thus allowing the cold oxygen itself to cool the metal. It was an ingenious scheme, but in the initial design the intense heat of the motor raised such sudden pressure that the oxygen tank ultimately exploded. The motor was cone-shaped; a direct descendant of the cavity in the sky-

rocket's fuel load. The nozzle, which projected out of the bottom of the oxygen tank, was about three inches long. Blast chamber, nozzle, and oxygen tank were made of an aluminum alloy, chosen for its lightness and the rapidity with which it conducted heat.

In their next attempt, the experimenters produced an oxygen tank which had a larger safety valve, and the motor also was larger. Its performance, however, was very much like the first. In both of these motors the fuels were introduced through separate inlet ports near the throat of the nozzle, and were forcibly injected upward by gas pressure.

The tests taught several lessons, not the least of which was that liquid oxygen is not a very satisfactory coolant. It also became clear that a cone-shaped chamber is not an effective design. The volume of the chamber is too small in relation to the area of its surface, and the sharp corners where the nozzle joins obstruct the rapid flow of the gases.

A later motor developed by these experimenters and demonstrated in 1931 to Mrs. Pendray and me as representatives of the American Rocket Society had many improvements. The motor was cooled by running water. The material was aluminum alloy, and the blast chamber was what the experimenters called "egg shaped," though inspection showed it to be cylindrical, with each end finished off in a hemisphere. The propellants came in through two ports near the throat, directed upward so the streams of liquid oxygen and gasoline would meet near the radius of the upper hemisphere.

This motor was small, weighing about a pound. It produced a thrust of about 20 pounds, at a calculated jet velocity of about 6,000 feet per second.

4.

Perhaps the best known complete series of motor experiments ever reported were those made under the auspices of the American Rocket Society between 1932 and the beginning of the second World War.

The society's first motor was based principally on German designs. I returned to this country with the ideas on which it was constructed following the *Verein für Raumschiffahrt* demonstration in 1931. The motor was not merely a duplication of the

German work. Made of cast aluminum alloy, it was considerably heavier than the German motor. The blast chamber was cylindrical, with hemispheric ends, and measured two inches in diameter and three inches in length. The nozzle was three inches long, with a half-inch throat and a taper of about ten degrees.

The inside of the nozzle was carefully machined and the inner

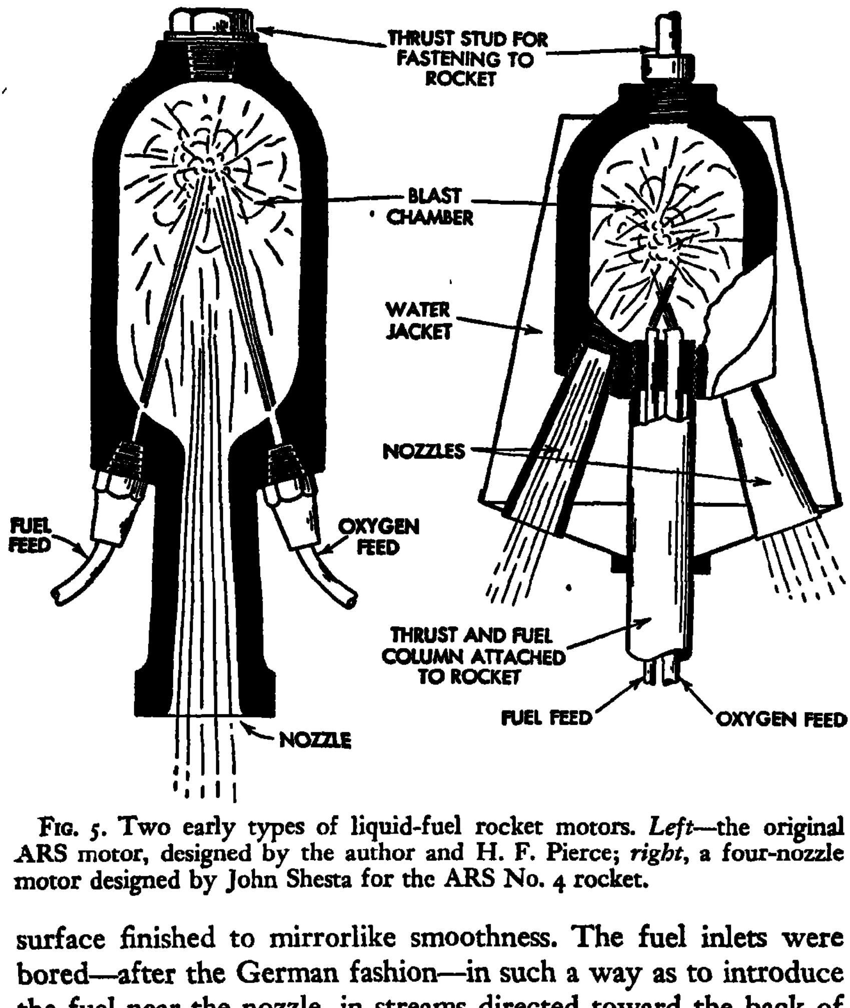


FIG. 5. Two early types of liquid-fuel rocket motors. *Left*—the original ARS motor, designed by the author and H. F. Pierce; *right*, a four-nozzle motor designed by John Shesta for the ARS No. 4 rocket.

surface finished to mirrorlike smoothness. The fuel inlets were bored—after the German fashion—in such a way as to introduce the fuel near the nozzle, in streams directed toward the back of the motor. The theory of this was, simply, that such a position for the inlets would make the fuel travel substantially twice the length of the motor, and thus provide for some cooling effect along the walls as well as better mixing and combustion. It was

an excellent theory, but subsequent experiences indicated that it did not work well in practice, and it was later abandoned.

The size of the inlet ports in this motor controlled the rate of fuel feed. The gasoline port was one-sixteenth inch in diameter; the liquid-oxygen port, just opposite it, was one-eighth inch in diameter, giving approximately four times as much oxygen, by volume, as gasoline. This was a high ratio of oxygen to gasoline, but it was thought better to waste some oxygen than to run the risk of incomplete combustion of the fuel.

The first test took place at a proving ground near Stockton, New Jersey, on November 12, 1932. The motor was mounted for the test between two pipelike cylindrical tanks, one of which contained liquid oxygen; the other gasoline under nitrogen gas pressure of 300 pounds per square inch. A water jacket surrounded the motor for cooling. The whole contrivance was fastened between two parallel upright wooden bars, on which it was free to slide against the tension of a spring. Previously the spring had been calibrated so that by measuring the distance traveled against its tension, the experimenters would be able to determine the thrust of the motor.

The report[4] on the first test, as published in *Astronautics* for November, 1932, read in part as follows:

> We had previously decided that the fuels should be turned on almost simultaneously, the oxygen first, the gasoline close behind. I judged that the fuse was going properly to light the fuels. About three minutes had passed since the final turning down of the oxygen valve. Enough pressure should have been built up to start the firing. . . .
>
> Mr. Pierce (H. F. Pierce, later president of the society) threw his switches rapidly. The fuse apparatus worked to perfection. For an instant there was a great fire, as the pure oxygen struck the burning fuse.
>
> In an instant the gasoline was also pouring into the rocket. The fuse, the flare, and the uncertainty about the performance of our rocket motor all disappeared at once, as, with a furious hissing roar, a bluish white sword of flame shot downward from the nozzle of the combustion chamber, and the rocket lunged upward against the retaining spring. . . .
>
> The flame was about twenty inches in length, clear and clean, of a bluish-white color, and quite steady. There was

[4] "The History of the First A.I.S. Rocket."

> none of the chugging, choking or backfiring we had expected. The sound was even and powerful throughout the test. At the last, just before the firing ceased, the noise changed a little in quality—an indescribable change, perhaps a little less powerful. For a moment most of us thought the motor was hot, and about to burst. Now we believe this change in sound indicated that the liquid oxygen had been exhausted, and that the flame thereafter was supported for a second or so by the oxygen which flowed under pressure from the tank.
>
> Suddenly we knew that the oxygen supply had been exhausted. There was an excess of gasoline, as we had planned. This now came spurting out, throwing a shower of fire around the foot of the proving stand. . . .
>
> We made an immediate examination of the rocket. The water in the cooling tank was hot, but not too hot to touch. The nozzle of the motor was clean and bright, showing no sign of scoring or pitting. Inside the narrowest part of the nozzle there was a little soot, which very probably was left there by the final charge of gasoline. . . .
>
> But most important—the marks made by the rocket on the soaped guides indicated that it had registered a lift of sixty pounds. . . . Our fifteen-pound rocket would, in a vacuum, have ascended to a height of sixteen miles. Discounting liberally for air resistance, a well-designed rocket, flying perfectly straight, ought with so much power to reach an altitude in air of five to eight miles.

These enthusiastic comments about the motor turned out, however, to be too optimistic.

In subsequent tests it scored badly, and a whole sequence of motors like it, both with and without water jackets, burned out with disheartening regularity when tested against standard conditions on a proving stand especially constructed for the purpose.

The society had phenomenal luck with its first test. It is not known to this day why the motor stood up so well for that first shot or so, and later showed its weakness all too plainly. It was that kindly Providence, no doubt, which is traditionally said to watch over rocket experimenters.

5.

A rocket motor produces so much quick power, and speeds on its way so fast in flight that it does not have to burn very long in

any one shot to go a long distance. But more than a few seconds are usually necessary, and the need, except for military rockets, is to develop a motor that can be used repeatedly, for whatever length of time might be desired, without danger of burning out.

Pursuing this objective, the experimental group of the American Rocket Society subsequently gave almost five years (working week ends and evenings principally, since this was an amateur occupation) toward the development of successful motors capable of firing for indefinite periods, and developing high thermal efficiency.

The first step was the construction of a suitable proving stand. To provide a cheap and easy method of getting data on many types and shapes of motors without building completely new models each time, a sectional motor was developed which made it possible to exchange some parts—for example nozzles—without any more trouble than the undoing of a few clamps.

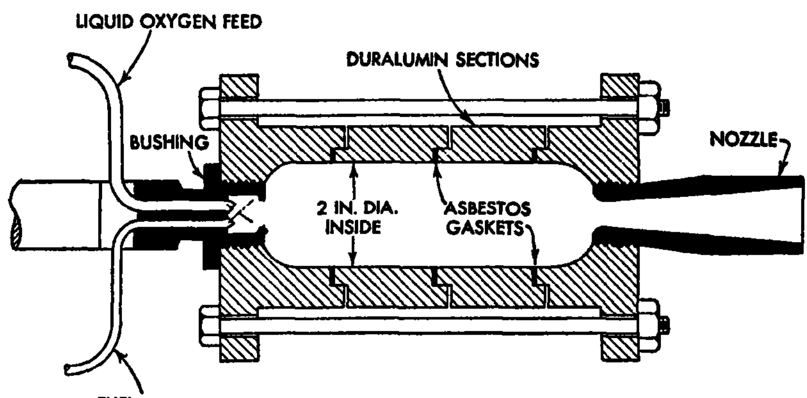


FIG. 6. Sectional liquid-fuel motor used in the American Rocket Society's test stand experiments.

With this proving stand, followed subsequently by bigger ones and additional refinements, it was possible to try a great many types of motors and motor parts. It was possible, too, to prove to the satisfaction of all concerned that simple cooling schemes, such as water jackets, ice bags, dry-ice packs and the like were quite ineffective if the shot were to last more than a few seconds. Air-cooling likewise proved ineffective.

Turning next to metals and materials which it was believed would withstand the heat without special cooling, the experi-

menters performed tests with ceramics and fire clays of various types, with hard metals such as Stellite, with Nichrome and other heat-resistant metals, and with blocks of pure carbon serving as nozzles. The ceramics and fire clays cracked rapidly under the change in temperatures in the motor. The heat-resistant metals soon proved to lack sufficient heat resistance. The carbon had too little strength; motors made of it burst promptly. All other materials likewise failed with disheartening certainty.

By the end of the first series of tests, it was clear that none of these schemes would produce a permanent non-melting motor. The experimenters next turned to studies of ways in which the incoming fuel or the liquid oxygen could be made to do the cooling. The experiences of the Germans with liquid oxygen as a coolant brought this suggestion into early disrepute. Using the oxygen in this way simply caused it to boil furiously and vaporize before it could get into the blast chamber.

The fuel, however, offered a source of cooling that had possibilities. Most of the suggestions for ways to introduce the fuel around the nozzle—the place of most serious burning—were complex and cumbersome, and had to be discarded. Then James Wyld, a member of the society's experimental committee and later its president, came forth with a simple, practical "self-cooled tubular regenerative motor" and the problem began to be solved.

Mr. Wyld was not, of course, the first to suggest the use of the incoming fuel as a coolant. This was also proposed by Hermann Oberth, the German theorist and experimenter; by Dr. Goddard, by Harry W. Bull, by Dr. Eugen Sanger of Vienna, and many others. Though he has not disclosed the details, it is probable that fuel cooling was the method used by Dr. Goddard in his successful motors. Mr. Bull used a regenerative motor, apparently cooling only the nozzle, about 1933. Dr. Sanger was using fuel-cooled motors as early as 1934.

Mr. Wyld's motor was significant because of the simplicity of design, inherent lightness and practicality. It was a significant accomplishment also because the inventor freely published the design of his motor in *Astronautics* for April, 1938. He made no attempt to patent the device, thus making it available for the advancement of rocket research everywhere.

The Wyld motor was simplicity itself. The blast chamber of

the first model consisted of an aluminum tube two inches in diameter and six inches long, to the lower end of which was attached a short, stubby Monel metal nozzle of very thin wall section—one eighth of an inch or less in thickness.

The blast chamber was encased in a second tube, just a trifle larger, so as to leave a cylindrical space about an eighth of an inch in thickness for the passage of the fuel. This double jacketing was carried to the nozzle also, but here the permitted thickness of the liquid layer was greater.

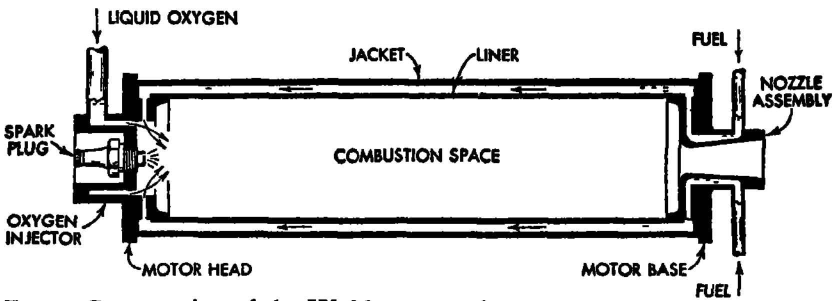


FIG. 7. Cross section of the Wyld regenerative motor as originally presented in *Astronautics*.

In such a motor the fuel comes in near the tip of the nozzle and goes into the coolant chamber surrounding the nozzle with a swirling motion. From there it passes rapidly through the passage surrounding the blast chamber, and thence to a mixing device at the head of the motor. From the mixer it is sprayed through a series of inlet ports, intimately mingled with liquid oxygen which is brought in at the motor head.

When the walls of the motor are thin enough, heat imparted by the escaping jet can readily pass through the metal and into the incoming fuel. The motor is called "regenerative" because it saves heat that would otherwise be wasted through the nozzle and the blast-chamber body, and brings it back inside the motor.

A regenerative motor that is functioning well remains almost cool to the touch, even after operation for a considerable time. When properly constructed it literally cannot burn out, for not enough heat accumulates in the thin section of the nozzle to permit either scoring, erosion or melting to an appreciable extent. As long as the fuel flows freely, the motor will operate.

In basic principle, the Wyld type of regenerative motor is the liquid-oxygen motor in use today in many an operation making

use of liquid fuels. It works almost equally well with liquid oxygen, nitric acid or other liquid oxidizers. Only the metals used in its construction need be altered to take account of the relative corrosiveness of some of these chemical combinations. To use nitric acid, for example, the inner part of the motor and its connections must be made of stainless steel.

6.

The regenerative motor has a quite pleasing by-product, which arises from its regenerative features, the length of the blast chamber and the general design: its thermal efficiency is excellent.

The efficiencies are now of the order of 40 to 45 per cent in larger motors of this type, corresponding to jet velocities of 6,000 to 6,500 feet per second or better with liquid oxygen and gasoline. This efficiency is still far from the theoretical maximum, but compared with the efficiency of the skyrocket, at 2 per cent, or the early motors of American experimenters, which were only about 5 per cent efficient, this is enormous.

A major part of the rapid wartime development of the regenerative liquid-fuel motor in this country has been due to the research and engineering of Reaction Motors, Inc. This organization was established with the encouragement of the armed services in 1941 to develop and manufacture reaction motors of various types for military and peacetime uses. Its president, Lovell Lawrence, Jr., was formerly secretary of the American Rocket Society. The vice-president and chief engineer, John Shesta, is a former chairman of the society's experimental committee. James Wyld, now president of the American Rocket Society, is the company's secretary and principal research engineer. Test engineer is H. F. Pierce, co-designer of the Rocket Society's first liquid-fuel rocket, and a former president of the society.

A regenerative motor for liquid oxygen and gasoline has recently been developed by Reaction Motors capable of continuous operation at a thrust of more than 3,000 pounds. The motor itself with its auxiliaries weighs less than 75 pounds, and its efficiency is such that a properly constructed rocket powered by it could probably be shot at least 100 miles high, or to a trajectory distance of more than 250 miles.

Before the war motors of 100 pounds thrust were considered large. Now it would be quite possible to construct them at least 1,000 times as powerful as that. It seems quite probable, too, that thermal efficiencies will improve to the point where jet velocities of 8,000 and even 9,000 feet per second will be readily obtainable.

Chapter IV

Air, Flame and Power

1.

So FAR as the records show, the first man ever to ride an aircraft driven by rocket power, in a witnessed flight, was an otherwise uncelebrated German glider pilot named Frederich Stamer, who flew a Rhon-Rossitten Gesellschaft glider, equipped with two large dry-fuel rockets, in the Rhon Mountains, Germany on June 11, 1928. The Gesellschaft was a large glider society, and the purpose of the flight was ostensibly to test the possible use of rockets to assist gliders in taking off.

> After a flight of 200 meters in a direct line, during which the machine rose gently [Stamer reported later], I turned in a curve through about 45 degrees and continued in a straight line for 300 meters, followed by another curve through 45 degrees. At this point the first rocket was burned out and the second fired, enabling the flight to be continued.
>
> This time I flew 500 meters in a straight line, turned through 30 degrees, and after a further 200 meters I brought the machine gently back to earth, shortly before the expiring of the second rocket. The total flight was from 1,300 to 1,500 meters (about 4,900 feet); the total time was 60 to 80 seconds. . . .
>
> Flight with jet propulsion I consider as exceedingly pleasant. Motor vibration and torque are absent; so that one has the sensation of pure gliding, and is reminded of the rockets only by their loud hissing.

A little over a year later another German, Fritz von Opel, an automobile manufacturer, flew a powder-rocket equipped glider at Frankfort, on September 30, 1929. The Opel glider operated entirely by rocket power, from takeoff to landing. It flew about a mile.

The Opel flight, like Stamer's, was an historical rather than a scientific achievement. Because powder rockets were used, the

flights were necessarily of short duration, were uneconomical as to fuel consumption, were little more than spectacular publicity stunts.

But they were prophetic, for the Stamer and Opel flights were the beginnings of jet propulsion in aircraft. These two light gliders, one so weakly powered it required help from a tow-rope to get off the ground, were at least the spiritual ancestors of the British, American and German propellerless aircraft which began to appear in 1943—and also the huge jet-driven, high-flying airplanes still to come, which will provide a new horizon for aviation.

2.

The Stamer and Opel jet planes were not practical because they sought to make use of the wrong kind of motor. There was no inherent reason why jet propulsion could not be applied to the powering of aircraft as well as to projectiles, but the power plant certainly needed to be tamed down, its jet speed reduced, and its fuel economy at relatively slow speeds improved.

A proper reaction motor for aircraft must first of all be able to operate with suitable efficiency at speeds reasonable for an airplane—that is, at velocities lower than that of sound, and possibly as low as 300 to 400 miles an hour. If there are to be moving parts in the engine, they must be few, simple and light. The motor must be able to deliver greater power than a reciprocating engine of the same weight, and it must be able to draw its oxygen, as the reciprocating engine does, from the air.

The general type of reaction motor that meets these conditions of course is the airstream engine, of which the best known variety is the thermal jet engine. This title has been variously shortened for conversational purposes to "jet engine," "turbo-jet," "jaypee" or "swish," depending somewhat on the engine being described and the impatience of the speaker. The Germans refer to their versions of the thermal-jet engine as *Heissluftstrahltriebwerke.* The French appellation is *thermo-propulseur.*

Already a great many varieties of airstream engines have been proposed or constructed, some good, some soso, and some that will as yet not work at all. Basically they all depend on the same reaction principle as the simple rocket motor, and hence are a true form of rocket power. But the aircraft designer who wishes

to use jet propulsion must particularly remember that the *mechanical efficiency of the reaction motor depends upon its speed, and is highest when the motor is moving at the velocity of the ejected gases.*

If he plans to use fuels and motors such as we have been discussing in the previous chapter, he will be confronted with the necessity of driving his plane at speeds up to one or two miles a second—an obvious impossibility at any practical flying altitude.

He must therefore develop a reaction motor which works on a rather different plan from that considered ideal for rockets or other jet-driven projectiles. He must produce a jet that moves at relatively low velocity. In order to make up for its small energy at such speeds, he must arrange somehow for the slow-moving jet to eject large masses of material; so that in spite of the low speed of ejection the product of the velocity times the mass will be high enough to provide the necessary thrust.

Unless the plane takes off with an impossibly heavy load of fuel, there is only one place where this large to-be-ejected mass can come from—the atmosphere. The air through which the plane is to fly is four-fifths inert matter; nitrogen and traces of other gases—and one-fifth oxygen, which can be used to support combustion of the aircraft's fuel.

What is needed is a simple, rapid means of drawing into the motor a large volume of air, burning fuel in it to provide an adequate supply of heat energy, and ejecting the result: nitrogen, oxygen and products of combustion, at relatively low velocity.

As long ago as 1908, the French engineer René Lorin suggested that a properly constructed reciprocating engine of rather ordinary type could be made to drive an airplane by jet propulsion instead of with a propeller, if the exhaust ports were so arranged as to provide a series of jet nozzles of the right size, shape and output—and of course pointed in the right direction. In such a device, the reciprocating engine would serve not to turn a propeller, but to compress air, mix it with fuel, burn it, and provide a series of reaction-producing pulses of hot gas.

Lorin did not build his proposed jet engine. It would probably have proved a cumbrous and inefficient means of achieving the end he had in mind. But he did succeed in pointing out to other fertile minds the possibilities in this direction.

In the following year, 1909, another French engineer, Paul

Marconnet, took out a French patent in which he set forth four different methods by which he thought the problem might be solved.

He proposed (1) that the jet could be produced by blowing air through a carburetor into a cylindrical combustion chamber, where it could be burned, the resulting gases to be jetted through a long nozzle; (2) that substantially the same system be used, but the combustion chamber might be cone-shaped to provide better control of the flame; (3) that the fuel and air be mixed in a sort of double-acting blower system, and injected intermittently into the combustion chamber by the second blower, and (4) that the intermittent action be produced by a flap-valve and only one blower, as a means of simplifying the device.

In these early suggestions, made at a time when the airplane itself was in its most rudimentary stages and flights as fast as 200 miles an hour seemed unattainable, Marconnet not only set forth the basic principles upon which all airstream engines to this day are based, but far ahead of his time he established the fact that there were inevitably to be two quite different and competing varieties: those that operate continuously and consequently have to force air into the blast chamber against the back pressure of combustion, and those that operate intermittently, thus avoiding the back pressure problem, but at the expense of delivering power only part of the time.

Another early explorer of this field was Christopher Lake, father of Simon Lake, the noted American naval architect, engineer, and inventor of the submarine. In the same year that Marconnet was presenting his ideas in France, Christopher Lake was applying for a patent in the United States for a type of reaction motor in which air was not only used to supply oxygen for the burning of the fuels, but was also mixed in additional quantities with the exhaust gases, to increase the ejected mass.

He thus became the father of a whole series of devices later to be known as thrust augmenters. This idea of using a rocketlike jet to force large quantities of air through a tube, producing a massive, slow-moving propulsion jet, became very popular.

Thrust augmenters were studied and designed and discussed by many engineers. The most elaborate were proposed by Henri F. Melot, a French engineer, who patented some in 1920. Melot was of the opinion that if one thrust-augmenter tube is good, more

should be better. In some of his schemes several such tubes were proposed. The jet from the combustion chamber was to be directed first into a small venturi tube, which in turn was to deliver its jet to a larger one, and so on. In this way successively larger tubes were to co-operate in producing a final massive jet.

Though Melot's name is still most usually attached to suggestions of this type (he picturesquely called his thrust augmenter a *propulseur trompe*, or "thrust horn") many other inventors and experimenters made similar proposals. The thrust-augmenter idea did not get a very serious testing, however, until about 1927, when two investigators undertook to study the Melot type of thrust augmenter, to see whether it had any real value as a means of propelling aircraft.

The investigators were E. N. Jacobs and J. M. Shoemaker, of the Langley Memorial Aeronautical Laboratory. Their general conclusions were that, while thrust augmenters do indeed increase the thrust of a fast jet to a large extent, the increase is not enough to make this device a practical method for aircraft propulsion.

However, this may not be the final word on the subject. Some experimenters insist that the thrust-augmenter scheme will work, and that it is potentially much simpler than any of the other ideas so far developed or proposed for driving aircraft by jet propulsion.

3.

Basically any true airstream engine will require four functional parts: (1) a means of drawing into the motor a large supply of air, (2) a method of compressing it somewhat, (3) a place to burn fuel in it to provide heat-energy, and (4) a suitable discharge nozzle to direct and control the jet.

The principal initial problem is how to get the supply of compressed air. For this, some sort of compressor will probably be needed—and to drive the air compressor there will be required some source of rotating or reciprocating power.

Now this problem can be solved very simply, if we are willing to accept a few moving parts. The general scheme of such a device, the thermal jet engine, is shown in the diagram.

Air is sucked into the front part of the engine, where it is compressed by the rotary compressor and passed under pres-

sure into the combustion chamber. Here fuel is injected into it through nozzles, and burned. The highly accelerated gases, given considerable additional velocity by the burning of the fuel, are forced to pass through the turbine wheel, and thence into the exhaust nozzle, where they perform exactly as in a rocket motor jet, imparting thrust to the engine in the direction shown by the arrow.

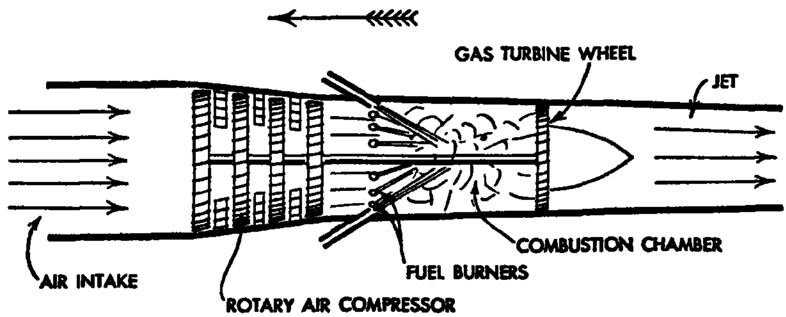


FIG. 8. Scheme of the thermal jet engine.

The turbine wheel is simply a small windmill, designed to operate at high speed and high temperature. It takes some of the energy of the jet, and transforms it into rotary motion. Since it is mounted on a common shaft with the rotary air compressor, this energy is used to draw air into the combustion chamber and thus maintain the process on a continuous basis, so long as burning fuel is fed into the chamber.

This is the turbine thermal jet engine, more popularly known as the "turbo-jet." The diagram does not depict any specific design but it is the general plan of all airstream engines which use a turbine for power to operate the air compressor.

Jet engines put forth by designers in France, Germany, England and the United States provide many ingenious variations of this general scheme. A variety of proposals have been made as to the types of air compressors to be used. Suggested fuels to be burned range from standard airplane gasoline to kerosene, fuel oil and even powdered coal, either mixed with oil or blown into the chamber through special nozzles. No matter what the variations, however, the turbine jet engine is simple, free from any need for crankshafts, cams, gears, pistons or special fuels, and, in driving an airplane requires no propeller.

Jet engines are now undergoing rapid development, responding to the need for new types of planes that can climb fast, fly high, and that require no special, costly fuels. Not a little of this development has been made possible by the recent appearance of new alloys of high strength, able to perform at high temperature. Several alloys of this type now used for turbo-jets, were originally developed principally for the blades of high-temperature, high-pressure steam turbines, for turbo-supercharger blades, and the like. Visitors to the Westinghouse exhibit at the New York World's Fair of 1939 may remember seeing one of these high-temperature alloys, known as K-42-B, compounded of five different metal ingredients, and shown in a demonstration aptly called "hell's bells."

The demonstration consisted of two small metal bells, one of ordinary carbon steel, the other of the new alloy. At room temperature, both bells rang about equally well when struck with a hammer. But when heated to a bright cherry red, the carbon-steel bell gave out only a sodden "tunk," while the bell of high-temperature alloy rang like silver, and actually had strength as high at this heat as the carbon steel when cold.

These metals are undoubtedly only forerunners of alloys still to come, which will permit operation of jet engines at higher temperatures, under greater conditions of speed and stress.

In the turbo-jet, the high temperature problem is further complicated by the speed at which the apparatus must work. The rotor, which includes the rotary air compressor, the turbine, and their common shaft, must spin as no engine rotor ever spun before. In order to compress air rapidly enough to maintain suitable operation, this apparatus must turn over 15,000 to 17,000 times per minute—so fast indeed that the rotor of one type now in operation attains a peripheral velocity of over 16 miles a minute—nearly 1,000 miles an hour.

Under such conditions the centrifugal forces acting on the blades of the turbine and compressor are enormous. The clearances between the edges of the blades and the casing must necessarily be kept very small, in order to prevent leakage of air or gas. At the high temperature at which the turbine operates when delivering maximum power, all metals tend to creep and deform. Consequently, these rotors present one of the most difficult metallurgical problems encountered in any machine.

Like most engines, the turbo-jet must also have some auxiliary apparatus. Starting is usually accomplished with the aid of an auxiliary electric motor or a tank of compressed air, for the rotor must be spinning when the fuel is turned in. Force-feed oil pumps are also needed, since the bearings of the main shaft are subjected to great stresses.

Ignition is required, too, at the start. An igniter must be carried along to restart the engine should it be shut down en route, or in case of trouble. A spark provides the necessary ignition.

Control of the power output of the engine is easy. It is managed simply by the rate at which the fuel is fed into the chamber. A single throttle does it.

4.

The most widely publicized "first flight" of an airplane driven by a thermal jet engine was that of August 27, 1940, when the engine designed by an Italian inventor, Secundo Campini, powered a plane flying from Forlanni airfield at Milan. The flight was short, lasting only about ten minutes—but so far as the engine was concerned, it was successful.

A little over a year later, a much more ambitious flight was undertaken with a similar plane and engine, piloted by Colonel Mario de Bernardi, a veteran racing flyer. Taking off on a Sunday morning, November 30, 1941, Colonel de Bernardi and a passenger, a Captain Pedace, flew from Milan to Rome, a distance of about 300 miles. The flight took a little over two hours and included a stop at Pisa, apparently for fuel.

The Campini engine was a thermal jet engine, but not a turbo-jet, since it relied on an ordinary radial aircraft engine instead of a turbine to do this job. The radial engine was mounted behind the compressor in such a manner that the incoming air could cool the engine—and the engine's heat would thus add to the energy content of the mass as it moved onward through the combustion chamber and the jet.

The fuel consumption was rather high, which was to be expected—but the contrivance flew. The Italian newspapers gave it huge space in their columns—and perhaps they were not exaggerating when they hailed it as the prelude to a revolution in the design of aircraft power plants.

The Campini engine had hardly cooled off, however, before

rival—and improved—jet engines began to appear. Word came out that at least one of them had even beaten the Campini to it. A jet engine designed by Captain Frank Whittle, a young British engineer and Royal Air Force officer (subsequently Wing Commander Whittle) had powered a full-sized airplane in flight as early as 1939.

The flight received no publicity at the time, and apparently the first mention of it in this country was some weeks later, in the aviation section of the New York *Times*. The *Times* described the engine in some detail, and disclosed it to be a remarkable engine indeed. Since it made use of a turbine, it was well ahead of Campini, both in time and design.

> The invention [reported the newspaper], consists primarily of a centrifugal compressor, a turbine, a combustion chamber with propelling nozzles through which the gas is discharged to propel the plane. The unit is arranged so that the compressor continuously draws large quantities of air from the atmosphere through an opening in the front of the plane, and, compressing it, passes it on to a combustion chamber, through which it flows continuously, receiving heat as it does so from the combustion of oil fuel, the heating thus taking place at constant pressure.
>
> From the combustion chamber the air passes through nozzles to the buckets of a turbine, which is coupled to the shaft of the compressor. The expansion through the turbine is only sufficient to enable it to drive the compressor and a second expansion takes place through a nozzle situated in the after portion of the plane. The heating of the air in the combustion chamber increases the velocity of the air tremendously and it is the backward thrust of this airflow which provides the propulsion force for the plane.

How far in advance of general engineering thought was Mr. Whittle is made clear by other comments at this time. Even rocket experimenters were skeptical. A commentator, writing in *Astronautics*, remarked that "Mr. Whittle apparently has operated successfully a gas turbine. If so, this work is significant, for recent figures available on gas turbine operation and thermal efficiency indicate that within the temperature limitations of nozzle and blade metals, the power developed by the turbine alone is just enough to drive the compressor."

Nevertheless, Whittle did it. The first "official" flight of a plane powered by the Whittle jet engine occurred in May, 1941. This gave Campini an eight-month lead so far as official results were concerned, but clinched for all time any doubt whether the Whittle gas turbine would deliver the goods. The pilot of this flight was Flight Lieutenant P. E. G. Sayers, chief test pilot of the Gloster Aircraft Company.

Two months after the official flight, in July, 1941, details of the Whittle jet engine were made available to the United States Army, and further development of the engine became a joint English-American project. One of Commander Whittle's engines was delivered to the General Electric Company at Schenectady, New York for study and production, and within a few months several American-made engines had been built and tested. The Bell Aircraft Company was charged with the responsibility of developing a suitable airplane to be driven by the new engines, two to a plane, and on October 1, 1942, Robert M. Stanley, Bell's chief test pilot, made the first American flight.

It was only a short flight, lasting thirty minutes, and the altitude reached was about twenty-five feet. Immediately afterward, convinced that the engines were operating properly, Stanley took off again and went up to 4,000 feet. He returned to the ground to remove the cockpit cover for better ventilation, and took off for a third time. This time he climbed to 10,000 feet, and flew for twenty minutes.

From Commander Whittle himself, remarkably little has been heard. He is a shy, quiet man, and a hater of publicity. When news of the British and American flights with his engine was finally released, in January, 1944, he is said to have exclaimed: "This will mean that I shall be known throughout the world. I am completely embarrassed—I wish I had become a doctor!"

The Whittle jet engine appears to have been the first successful turbo-jet to reach the production stage. It soon had rivals, some of them with clear advantages over the British design. American manufacturers, urged to the task by military authorities, began to bring out improvements and independent designs, with a view to producing jet engines with greater efficiency, smaller diameter, less weight and lower fuel consumption.

The first all-American turbo-jet engine, produced completely independently of European designs, was developed by the West-

inghouse Electric & Manufacturing Company for the Navy Bureau of Aeronautics. The Westinghouse engine, details of which are still undisclosed, made use of the new metal K-42-B, and was designed to operate at temperatures of 1200 degrees Fahrenheit or more. It produced more pounds of thrust per pound of weight than any engine at that time developed abroad.

It hardly need be said that European countries likewise joined the race. It was presently disclosed that the German Air Force had at least two models of thermal jet fighters in an advanced stage of development and by 1945 they were actively in combat. Even before the war, Swedish, Swiss and German manufacturing companies had been exploring the possibilities of jet engines.

The details of these engines—and for that matter, the details of the Whittle engines and their American counterparts—will have to await the lifting of the military censorship that now veils the subject. It is likely, however, that the sound of jet-driven airplanes will become increasingly familiar to our ears.

There is of course no propeller noise in this sound, though the compressors sometimes emit a shrill, almost supersonic wail that rings in the ears. What is principally heard is a loud roar, steady and powerful. To some ears the jet plane is less noisy than the propeller-driven craft; others find the sound no less loud—only different. To the pilot, the noise seems definitely reduced. He has no propeller screaming in front of him and the steady roar behind is less wearing on the nerves. Also, to some extent he is escaping from it—or part of it—as he flies.

Jet planes ultimately will travel at or above the speed of sound—at which velocity of course the pilot and passengers will hear nothing, since they will be leaving the sound behind.

5.

So far, apparently, the other types of airstream engines: the intermittent and continuous duct engines, have not been used to propel full-sized aircraft.

The most famous—or infamous—application of the intermittent duct engine is the German "V-1" weapon of the summer of 1944, the "buzz-bomb." This engine (see Chapter XI) may, however, have many peacetime applications, especially if its efficiency can be improved.

The intermittent duct engine is by no means a brand new idea. A version of such an engine was patented by Paul Schmidt, a German engineer, as early as 1930. The Schmidt duct engine consisted principally of a long tube, the forward end of which turned downward slightly and was fitted with a series of flap-valves resembling Venetian blinds. As the engine moved rapidly forward, the ram effect of the atmosphere was expected to force open the valves and admit air to the chamber, where fuel was to be injected into it and ignited. The resulting explosion was expected to close the shutters at the front, and force out through the rear a jet of air and the gases of combustion. A resulting low-pressure area behind the shutters and the continuing ram effect were then counted upon to reopen the shutters, admitting air to produce the next cycle.

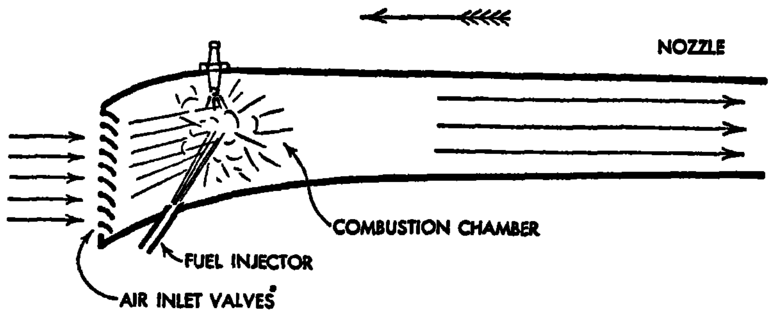


FIG. 9. Scheme of Schmidt's duct engine, patented in 1930.

Another type of intermittent duct engine, considerably more complicated, was proposed in 1932 by Wilhelm Goldau, also of Germany. Goldau's engine consisted of a long torpedo-shaped reaction chamber, fitted with valves at either end. At the beginning of each cycle, both valves were to be opened, permitting air to flow the full length. Then the fuel was to be injected, the mixture ignited by a spark, and the exhaust and fuel valves manipulated in such a way as to provide alternate cycles of charging and reaction.

Goldau planned to have these reaction chambers work in pairs, timed in such a way that the exhaust of one would provide thrust to force the air into the other. Three or more such pairs, he estimated, would be necessary to drive an airplane.

The continuous duct engine, which has been under develop-

ment principally in England under the curious name of "athodyd,"[1] is also a relatively old idea. Calculations indicate that this device, which consists of little more than a short tube, open at both ends, will not deliver its maximum power unless it is moving at or near the speed of sound, and it is generally considered as a device that shows some promise for auxiliary power in high-flying or very fast aircraft.

One of the earliest experimenters with devices of this sort was Bernard Smith, at that time a member of the experimental committee of the American Rocket Society. About 1935 Mr. Smith developed a small reaction engine of the continuous duct type which he called a "blowtorch motor." Essentially it was a tube open at both ends, into which a fine jet of burning gasoline was spurted through a small nozzle from a pressure tank.

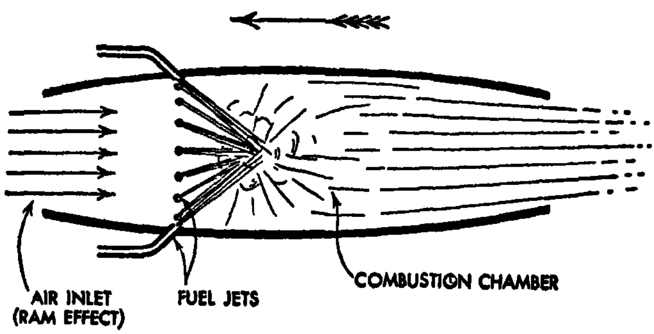


FIG. 10. Scheme of the athodyd.

In order to produce the motion needed to ram air into the tube the experimenter mounted the device on a long pivoted arm, with a counterweight for balance, in such a manner as to enable it to rotate in a circle about six feet across.

Ignited and given a little start, the "blowtorch motor" rapidly gained velocity and soon spun like a pinwheel. So far as I can learn, these experiments were never formally reported in any technical journal, but were witnessed by several experimenters, and on one occasion I took part in a test of the device. Mr. Smith, who was also busy at the time in the construction of an experimental liquid-fuel rocket, did not pursue the development further.

In its larger and more modern versions, the athodyd looks

[1] From the descriptive words "*A*ero-*Th*erm*O*-*Dy*namic *D*uct."

somewhat like a slightly elongated barrel with both heads knocked out. Gasoline is fed in through a ring of small orifices ahead of the middle of the duct. The air entering at the front is expanded and speeded on its way by the combustion of this fuel. The increased velocity induced by combustion provides sufficient jet reaction to keep the device up to speed and produce power for the aircraft to which it is attached.

As yet, too little is known about the potentialities of the athodyd to determine what its field of usefulness may be. Like the true rocket motors, it is the essence of simplicity and has no moving parts. If it can be brought to deliver power in practical amounts, it will prove a most inexpensive engine to construct.

Chapter V

The Rocket as It Flies

1.

In current writing and speaking about jet propulsion, there is often considerable confusion between the rocket itself and the motor that drives it. Sometimes rocket and motor are referred to as though they were one and the same thing. Perhaps this is quite natural since in some simple rockets, as for example the sky-rocket, it is pretty hard to tell where the motor leaves off and the rocket begins.

But a bit of reflection will make it clear that a true rocket is basically a projectile—that is, an object intended to be thrown or shot through the air or space. More particularly, it is *a projectile driven by jet propulsion.* A rocket differs from a jet-propelled airplane, therefore, principally in that the latter has wings, and makes use of the supporting power of the air during flight. The rocket follows a natural trajectory, and takes the air into consideration only as an obstacle or resisting medium to be overcome in the course of its flight.

As we shall see, the faster an airplane is to fly, the more it will need to resemble a projectile. The slower a rocket flies—especially during the process of landing—the more it will have to become like an airplane. At some undetermined velocity and area of use the distinction between aircraft and projectile will simply disappear. Just where that point must be is still something for the future and experience to decide.

Not much is known as yet about the necessities of faster-than-sound flight in aircraft, except that the teardrop shape of conventional airfoils will very probably have to be abandoned in favor of sharp leading edges and less bulky design. It has been said that the ordinary airplane would fly better at supersonic speeds if it went backward—that is, with the sharp edges of the

wings in the lead, and the ailerons at the forward edges instead of at the rear.

However, this change alone would probably not permit efficient supersonic flight. Very likely the entire airplane must undergo quite radical changes in shape. Tail surfaces may possibly disappear, and the supersonic airplane will perhaps resemble the much-talked-of flying wing—or maybe even the wedge-shaped paper darts we used to make as children at school.[1]

The whole field of aircraft design to make the best use of jet propulsion has, as a matter of fact, been quite neglected until recently. It offers one of the large new areas for future exploration and invention—a challenge to new thinking and fresh ideas. Most of the applications of airstream engines at present are not economical because the engines have in general been fitted to aircraft little suited for high velocities. The conventional airplane, designed for reciprocating engines and propellers, simply does not fulfill the requirements.

2.

On the other hand, the rocket has been subject of much investigation, and a great deal is known about the flight characteristics of jet-driven projectiles.

In its simplest form, a rocket must provide:

1. A means of carrying the motor in a way to exert its push most advantageously.

2. A means of carrying the fuel supply.

3. A way of feeding the propellants into the combustion chamber at just the right speed and in the proper proportions to maintain best combustion.

4. Steering or stabilizing gear.

5. A chamber or compartment for the payload.

6. Means of providing for the landing of the empty rocket at the end of its flight, unless it is expected simply to fall and be destroyed.

It will be seen that even the most rudimentary of rockets, the skyrocket, provides all of these, except the last. Its payload is the cluster of combustible pellets which are thrown violently burning

[1] See the proposed designs for supersonic jet-propelled aircraft in Plates VIII and IX as visualized by Jacques Martial and Robert Scull.

into the sky at the top of the flight. Its fuel compartment is the cylindrical body of the rocket, which also contains the motor. Its guiding apparatus is the stick that extends downward at the side.

No matter how small, large or complex the rocket, these six are basically all of the parts it needs, but their fitting together so as to produce a unified whole is often a thoroughly difficult job. When we begin to think of rockets in terms of tons instead of pounds, of trajectories in miles instead of feet, and velocities that approach or surpass the speed of artillery shells, rocket design presents one of the most exacting problems in modern engineering.

One of the first things the engineer must decide is how the propellant is to be carried—and if it is liquid fuel, how it is to be fed or driven into the combustion chamber.

If the rocket is to be propelled by dry fuels, the construction and design are relatively simple. The rocket motor and fuel chamber are almost inevitably one and the same, and the shape and arrangement of the rocket's parts are dictated by the range, the use to which it is to be put, and aerodynamic considerations.

In military dry-fuel rockets, the most usual arrangement is to place the warhead at the forward part of the rocket, followed by the fuel chamber and blast chamber, with the nozzle or nozzles behind. In the early part of the war, such rockets often had the familiar potato-masher shape which has been given the bazooka projectile (see Plate VII) and the German *Nebelwerfer* rockets. Later as ranges and velocities increased, the body of the rocket and the warhead tended to become cylindrical and continuous, with a sharp nose—a shape better calculated for high speeds through air.

In all such rockets the combustion chamber is integral with the fuel pack: either as a separate hollow near the rear or as gas spaces fluted or drilled into the fuel itself.

3.

The ease of stowing solid fuels into a rocket speaks strongly for using this type of propellant, of course, but as we have seen, there are also many drawbacks, not the least of which is that no known dry-fuel combination will yield as much energy, pound

for pound or volume for volume, as certain readily available liquid-fuel combinations. Rockets intended to go really long distances, or make very high velocities, or requiring control of the fuel feed during flight, will necessarily be designed for liquid fuels.

Here is where the engineer really begins to encounter some major headaches. Liquid-fuel rockets must carry their propellants in separate tanks: one tank for the fuel, another for the oxidizer. It does not do to let these violent substances get mixed in advance of their injection into the motor, for the result will almost certainly be a detonation instead of a flight.

Early experimental liquid-fuel rockets usually made an awkward business of the tank problem, aerodynamically. The first liquid-fuel rocket ever shot, Dr. Goddard's rocket of 1926 (see Plate XIV) placed one tank behind the other, and located the motor far ahead, on thin, ungainly supports of tubing. Some of the early rockets of the German experimenters, and the first two liquid-fuel rockets of the American Rocket Society, used parallel tubular tanks, with the motor mounted ahead or between them. Both designs are awkward and unsymmetrical; the only excuse for the arrangement was the comparative ease of construction.

The proper arrangement of tanks, of course, is the fashion known as "tandem-tank," where the fuel tanks, cylindrical in shape, are placed one behind the other to provide small cross-section and considerable length for the rocket. The most usual placement of the motor in such rockets is behind, where nothing need interfere with the free exit of its jet. Before the war this was already a more or less standard general design for all projected and experimental sounding and trajectory rockets. It was the arrangement used by the Nazis for the "V-2" rockets fired against England.

Regardless of the arrangement of the tanks, the method of forcing the fuels into the combustion chamber during the shot is a major problem. The liquids must be fed in with great rapidity, at an even rate, and under control.

In small experimental rockets, and probably in sounding rockets intended for reasonably high altitudes, this can be done most simply with gas pressure. If the oxidizer is liquid oxygen, it will even furnish its own gas for this purpose. If the tank is closed and the liquid permitted to boil a few minutes, the oxygen

soon liberates enough gas under pressure to thrust itself almost anywhere. Such tanks, of course, must always be supplied with safety valves or rupture discs set to blow off at pressures under the bursting strength of the tank.

The liquid fuel, whether gasoline, alcohol or whatever, presents more of a problem: it will not so obligingly furnish its own pressure. In small rockets the required pressure can be supplied simply by an inert gas, such as nitrogen, forced into the tank with the fuel. But if the liquid oxygen uses its own pressure, and the fuel is driven by pressure from another source, there is the probability that the two liquids will be fed at an uneven rate, resulting in poor mixture or waste of propellants. Moreover, as the liquids are used up, the space in the tanks occupied by the pressure gases increases and therefore the pressure drops, reducing the rate of feed, and further affecting the ratio.

To meet this, fresh quantities of pressure gas can be supplied from a separate container—a method frequently used in experimental rockets. It requires, however, that the rocket carry still a third tank—usually a small metal bottle of nitrogen under high pressure. The rate of fuel feed is equalized by providing the same pressure for both propellants from the nitrogen bottle, either directly or through pressure-reducing valves.

Naturally this solution results in more dead weight for the rocket to carry—for a pressure bottle is heavy. Some experimenters have tried to get around the need for a third tank by using the oxygen pressure to drive both the oxidizer and the fuel. It can be done in a variety of ways: the easiest—and most dangerous—being simply to connect the gas overchambers of both tanks with a pipe to carry the oxygen vapor into the fuel tank. Check valves can be put into the line, or tight-fitting pistons or floats inserted in the tanks to prevent the accidental mixture of the liquids, but no matter how it is done, the presence of oxygen vapor in the fuel tank is a considerable hazard, and may cause a premature explosion or destroy the rocket at the end of powered flight, through a flashback into the fuel compartment.

As a way of avoiding this hazard, James Wyld proposed in one of his designs to use a "hot-water bottle" fuel tank: a container made of collapsible material such as rubber or thin metal, which could be immersed either directly in the liquid oxygen or in a

separate chamber to which the oxygen vapor pressure could be admitted. Like the other oxygen-pressure schemes, it would work, probably, if everything went as expected. But it would be liable to undetected leaks, and to my knowledge has never been tried.

The worst trouble with the gas-pressure system of fuel feed, of course, is that it does not overcome one of the major difficulties complained of in dry-fuel motors: the need for high strength and corresponding weight in the fuel containers to withstand the necessary pressure. The propellant tanks must be strong, and proportionately heavy, because the pressure in the blast chamber will obviously always be somewhat less than that behind the incoming fuel. If it should momentarily become greater the fuels will simply stop flowing until the chamber pressure drops enough to permit them to resume.

As a matter of fact, frictional losses in fuel feed lines, valves and flow-control devices will absorb enough energy to require that the designer plan his tanks for pressures somewhat more than twice as great as those he expects to produce in his motor.

The only complete solution to the problem of fuel injection for long-distance rockets, where every last ounce of weight must be scraped out of the design in the interests of efficiency, will be pumps. Rocket fuel pumps have a most difficult job. They must be light, reliable, require little power. They must be able to handle the liquids rapidly, in controllable quantities, under conditions of extreme cold and extreme heat. And at least two will be required for a rocket: one for the oxidizer, the other for the fuel.

Many kinds of pumps have been proposed, some using a small portion of the propellants to supply power for their operation, some run by gas-pressure motors or gas turbines using a bit of pressure out of the motor itself, and some operated by separate propellants, as in the "V-2" rockets, in which the pumps were driven by high-pressure vapor produced by the chemical reaction of hydrogen peroxide and calcium permanganate.

Because in small rockets gas-pressure schemes are more economical of weight than pumps, there is as yet relatively little experience with the various possible methods of pumping the fuels mechanically. Obviously there is no advantage to pumps *per se*: they will be used only when they produce a weight

saving that makes up for their greater complexity, expense and possible unreliability. The chances are they will not be needed at all for rockets of relatively short range or small weight-carrying capacity. But for rockets intended to reach the outer atmosphere, or cover trajectories of more than 100 miles or so, pumps are likely to provide the best solution.

With suitable pumps the weight of the tanks can be materially reduced, permitting a better fuel-weight ratio, which in turn will result in longer firing time or greater power throughout the period of combustion. Obviously no single advance except the obtaining of higher jet velocities will do so much to increase the distance a large rocket can fly.

4.

The shape of an airplane is conditioned in general by two factors: what it has to carry, and the demands of aerodynamics at the speed and altitude intended. The shape of a rocket, however, is regulated almost altogether by the requirements of its flight; the payload has to find a place within the structure as best it can.

The conditions of fast rocket flight through the air are so severe that every part must necessarily be fitted into the pattern dictated by aerodynamic considerations. Such flight differs materially from the kind we are accustomed to observe in aircraft. It more resembles the flight of an artillery shell but still differs in important respects.

Typical rocket flight has four principal parts: the launching, the powered flight, the free flight and the landing.

The launching occurs as the rocket is given its initial direction by guide rails, launching tube, catapult or launching gun. The powered flight is the period of varying duration in which the fuel is burning in the motor and the rocket is being thrust forward. Free flight follows the completion of combustion, and under some conditions it may be the longest part of the shot. The landing covers the period during which the rocket, completing its course, comes back to earth.

These four are present in every rocket flight. A shot may thus be compared with the flight of an arrow, which has a launching period as it is guided over the bow by the hand of the archer, a

brief time of rapid acceleration while it is being driven by the taut bowstring, a long free flight during which it is simply a projectile spending kinetic energy to follow its prescribed trajectory, and the landing, during which it may plunge into a target, the flesh of an animal, or drop harmlessly to earth.

In the skyrocket, the launching is usually accomplished by letting the rocket guide itself through a tube or along a short trough. Sometimes amateur fireworks users simply stick the end of the guidestick in the ground, and let the rocket find its own

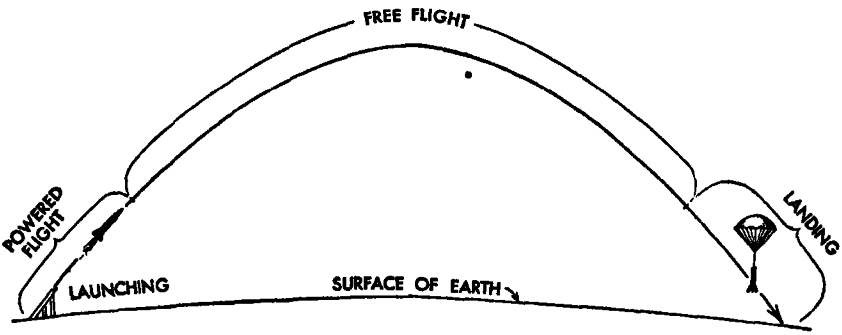


FIG. 11. Rocket trajectory, showing the four parts.

path into the sky. The powered flight of a skyrocket continues during most of the upward part of its trajectory. By the time it has burned its fuel and fired its stars there is so little mass remaining in the rocket shell—and its hollow carcass presents so much front to the wind—that it is quickly slowed down and forced to drop.

A metal rocket of proper design, however, with a more efficient motor, greater mass, and better streamlining, will act quite differently. On the same amount of fuel it might go many times as far, and after the powered portion of the flight is over it will continue on its way, using up the accumulated energy over a long period of free flight.

Obviously there is no need to power the flight all the way. We calculate instead the velocity that will be necessary to give our payload and the necessary permanent parts of the rocket sufficient energy to fly the desired distance as a cannon shell would do it. Then we provide the rocket with enough fuel to impart this velocity. We shoot the rocket from a launching

apparatus that will give it the best angle for our projected flight, and let it go.

Accelerated flight, such as the rocket will have during its powered flight, builds up speed very rapidly. The commonest example of accelerated motion is that of a dropping stone. Discounting air resistance, which is almost negligible at small velocities, a stone will fall about 16 feet in its first second, and will increase its velocity at the rate of a little over 32 feet per second each second afterward.

If we wish to know how fast it will be going at the end of any second, we apply a familiar formula: $V=gt$, where v is velocity in feet per second, g is the acceleration of gravity (about 32 feet per second per second) and t is the time in seconds. This formula shows that any object, whether stone or rocket, going at the acceleration of gravity, will at the end of its first second of flight be traveling at the rate of 32 feet per second, at the end of its second second, 64 feet per second; at the end of its tenth second, 320 feet per second, and so on. After it has been accelerated at this rate for one minute, it will be traveling at 1,920 feet a second. After somewhat less than three minutes, its velocity will be a mile a second.

An acceleration of only 32 feet per second ($1g$) is pretty slow for a rocket. Skyrockets have accelerations as high as $12g$, and some military rockets even more. Liquid-fuel rockets intended for very long flights will have smaller acceleration, however, because too rapid velocity before the upper atmosphere is reached costs too much in wind resistance. Experimental liquid-fuel rockets usually have accelerations of $3g$ or thereabouts. At this acceleration, the speed of a mile a second will be attained after slightly less than one minute of firing.[2]

The actual distances traversed in a brief time, even at the acceleration of gravity, are surprising. For example, in its one minute of flight, the one-gravity rocket mentioned above would not only be going 1,920 feet a second at the end of its first minute of firing, but it would already have traveled about ten miles. If its powered flight had been directed upward at an angle of 45 degrees, and it had been able to keep this direction, it would

[2] All of these calculations, of course, ignore the effect of air resistance, which varies considerably with altitude, velocity, the shape of the rocket and other factors.

have reached, by the end of its first minute, an altitude of nearly eight miles.

If the fuel were exhausted by this time, the rocket would pass over into free flight, with a trajectory the same as though it had been fired from a gun at that altitude, with a velocity of 1,920 feet per second, which means that, continuing to discount air resistance, it would fly a further distance of about 25 miles before coming to earth, making a total distance, from start to finish, of between 30 and 35 miles, all on one minute of firing, plus free flight.

Of course, this is a much simplified example. It is calculated without including the effects of wind resistance, the relative masses of the rocket and the starting fuel, the effects of gravitation on the powered flight and other matters which would change the results materially in an actual shot. It does indicate, however, the extent to which flight can be affected by savings in rocket weight which can be used to increase the fuel supply. For if the fuel of our theoretical rocket had been sufficient to last twice as long, giving the rocket an acceleration of 1*g* for *two* minutes instead of one (and note that this would not take anything like twice as much fuel, since the mass of the rocket is rapidly declining as the fuel is burned), the resulting shot would be something like this:

Velocity at end of powered flight:	3,840 feet per second
Altitude at end of powered flight:	30 miles
Distance (horizontal) covered in powered flight:	30 miles
Distance covered in free flight:	115 miles
Total distance:	145 miles

We would thus have provided more than a fourfold increase in total distance by doubling the firing time. Or we could have accomplished the same result in one minute of firing by doubling the rate of acceleration.

However, let us be careful not to overlook the difficulties. The basic problem of the rocket engineer is considerably more complex than our example suggests. We have dealt with only one—but the engineer must bring together in a single solution *all* the

variables affecting flight: mass, fuels, controls, wind resistance, change of mass in flight, effect of gravity, effect of the earth's curvature and rotation, drift, windage, etc., to produce the result desired. These variables are so many, and the problem so difficult mathematically, that in practice much experimentation is necessary to provide the solution even after the calculations have all been worked out on paper.

5.

Compared with the precision obtainable when artillery shells are fired from rifled guns, rockets as projectiles are often quite inaccurate.

The inaccuracy results essentially from two effects. First, since the rocket carries its own source of power, directed along the flight axis of the projectile, any small deflection occurring in the early part of the flight will be greatly increased by the thrust of the motor, which will necessarily take up the new direction in which the rocket is headed. The likelihood of such early deflection is enhanced by the fact that in the first part of its flight the rocket will be moving relatively slowly, and can be much affected by wind, vibration in the launcher, and other outside causes.

The second difficulty is that as the fuels are used, the projectile rapidly loses mass. This loss may and usually does act to shift the center of gravity of the rocket.

Objects moving through the air perform as though all their weight were concentrated in one single point, the center of gravity. When an airplane or a cannon shell turns in flight, it turns as though this invisible center of gravity were the pivot upon which the motion takes place. The stability of the center of gravity therefore is important. Shifting the center will inevitably affect the behavior of the projectile in its course.

A skyrocket becomes nose-heavy as it progresses: as the fuel in the body of the rocket burns up, the center of gravity moves forward. In short flights this makes little difference, except to give the tail structure (the guidestick) more leverage to keep the rocket headed firmly into the wind. If the reverse were true, and the center of gravity moved backward, great instability would result. The stick would have relatively less leverage, and the

wind on the head of the rocket relatively more, tending to thrust the nose aside.

For this reason most dry-fuel rockets are arranged so as to lose weight behind, and thus shift their center of gravity forward as they consume fuel. Whatever change of stability results is either of little moment, or is partly deprived of its effect by the brevity of the powered part of the flight.

Liquid-fuel rockets usually consume their fuels more slowly and present a more serious problem in this respect. One of the items which the designer must consider is whether the tanks can be arranged in such a way as to maintain the center of gravity steady as the fuels are consumed. There are a number of ways in which this can be done. The tanks may, for example, be concentric, or they may be placed in the middle of the rocket, with motor and controls behind and payload ahead in such a manner as to counterbalance each other.

The real heart of the inaccuracy problem in rockets, however—the danger of early deflection—is not so easy to handle. Early experimenters thought this could be overcome to some extent by placing the motor—and hence the point of thrust—well ahead of the center of gravity.

This merely adds, however, to the difficulties of design; it usually puts some part of the rocket in a position to interfere with the free escape of the jet, and adds nothing whatever to stability. Since the thrust is directed along the axis of the rocket, it makes no difference whether it is in front, behind or in the middle. It will always push the rocket in the direction in which the rocket is aimed.

More important than the location of the motor is good aerodynamic design. Since all rockets must fly some part of their journey in the air, the atmosphere is the most important single deflecting factor likely to be encountered.

The effect of the resistance of the air is conditioned by how fast the rocket is expected to fly—and how far, and at what altitudes. If the flight is to be brief, and the speed is to remain below the velocity of sound, the rocket can be made fairly stable in flight and still have a bulbous nose and a generally "streamlined" shape. The familiar "bazooka" projectile, shaped not unlike a slightly modified wooden potato masher with the big end foremost, is intended for moderately slow flight. There is, of

course, some pointing of the forward end, but in general the projectile conforms to accepted contours for subsonic flight through air.

If the rocket is to reach speeds faster than sound such potato-masher streamlining is worse than useless. At supersonic velocities the air can no longer get out of the way in front. It piles up, smothering the rocket; it must be pierced. Required for such velocities is a long spear-shaped rocket, of small cross-section, with a sharp nose. Fast, long-distance rockets will probably look somewhat like giant darning needles, with noses meant for penetrating the air.

The tanks of such rockets will need to be carefully balanced, both full and empty, and in all stages between. The fuel feed will need to be arranged so as to leave the center of gravity substantially unaffected as the liquids are used up. Even then, some special means of guiding will be required; so many external forces will affect it during flight it will be almost impossible for the rocket to reach its destination accurately by aim alone.

6.

Even in simple vertical flight, which would seem to be the easiest of all courses on which a rocket could be sent, steering presents many difficulties.

In high-altitude military rockets, such as those intended for use against bombers and other aircraft, flight-control mechanisms are dispensed with for the sake of simplicity and lightness. Lack of accuracy is made up by shooting the missles skyward in clusters, producing a sort of shotgun effect; if some get off course, others will reach the proper place more or less by chance.

Experimental rockets, however, particularly liquid-fuel rockets carrying instruments for sounding or research, will certainly require some kind of control mechanism to maintain vertical flight. Best aerodynamic design is a first essential, but without controls no rocket can assuredly make a true high-altitude shot.

This is no easy problem. Controls by the dozens have been devised by experimenters which depend on pendulums and drops of mercury in U-tubes, all relying on gravity to give true vertical direction. These methods fail, because the acceleration of the rocket is usually greater than the acceleration of gravity.

There is really only one device that will do the work: the gyroscope. This instrument, because of its ability to maintain its position in space regardless of the external forces acting upon it, is the "brain" of such instruments as the artificial horizon in aircraft, the automatic pilot, and the control mechanism of submarine torpedoes. The gyro alone can determine vertical flight for a rocket, regardless of the rocket's acceleration, velocity or other conditions.

It consists simply of a wheel spinning rapidly on its axis, mounted in gimbals in such a way as to permit movement in any direction. When it is spinning rapidly, the gyro wheel resists any attempt to change the position of its axis with relation to space. But if enough torque is applied, as indicated by the arrow, the gyro will *precess*, that is, will react at right angles to the deflecting force.

For rocket use, a very small gyro is necessarily indicated. The instrument inevitably adds weight to the rocket, and we must accept as little as possible. A small gyro cannot by itself keep the rocket on course; it must be harnessed to other mechanisms so that it need serve only as an indicator of the true direction. No twist or torque may be placed on the gyro itself, or it may precess and spoil everything.

These requirements make the control mechanism even for simple vertical flight a rather complex affair. Power must be furnished from some source to operate the gyro wheel, some means must be provided of transmitting the gyro's direction to detecting mechanisms without affecting the gyro in the process, and a servo-mechanism must be devised capable of bringing the directional control to bear on the actual flight of the rocket.

If the rocket is already supplied with pressure gas, some of it can be tapped off to drive the gyro. Gas pressure can also be used to detect off-course indications given by the gyro, and either gas pressure or hydraulic systems can multiply and transmit these signals to fin surfaces or vanes in the blast of the motor, to correct the rocket's course. If gas pressure is not present, electrical or magnetic systems may be devised, but these require carrying a battery or other source of power.

Successful gyro-control systems, adaptable to rockets with some minor changes, can be produced commercially. After the

war it is likely that excellent ones will appear, both for vertical guidance and for directing large rockets on trajectory courses.

7.

We have still to consider the problem of the rocket's landing. Obviously what goes up must come down; and according to the laws of physics a rocket will strike the earth after free fall at about the same velocity as that which it attained in making its ascent.

When the rocket has served its purpose after a single shot, or when it contains no fragile or valuable payload, the landing is a matter of small moment. Skyrockets are permitted to drop where they will: once shot they are thereafter useless. Military rockets likewise merely fall at the end of their trajectories, or are caused to explode in the air.

When the rocket carries instruments or other valuable payload, however, some means of providing for a gentle landing is required. The most obvious device for this job is the parachute, and virtually all small liquid-fuel rockets are provided with them. Even very large, high-altitude rockets may be landed quite well with parachutes. If the rocket is intended to shoot into the stratosphere, it will probably be equipped with a pilot parachute as well, to commence the deceleration and thus reduce the sudden shock when the main chute opens.

The placement of the parachute on the rocket has been the subject of much debate among designers. An obvious location is at the front of the projectile, where it is well out of the way of the motor's blast, and can be packed into the pointed nose with little difficulty. The trouble with placing it there, however, is that the rocket may yaw over and start earthward nose-foremost before the parachute is ejected, in which case the chute may simply become tangled in the rocket and refuse to open.

Some experimenters maintain that the only suitable place for the parachute container—the "chute boot"—is at the tail of the rocket. In nose-drive rockets this placement presents little difficulty, but in the type of rocket which carries its motor at the rear, the parachute must be stowed in a compartment ahead of the motor, and provision made to eject it sidewise so it will clear the motor and fins.

Various types of wing mechanisms have been suggested by experimenters to take the place of the parachute. Reinhold Tiling, a German engineer, developed a series of dry-fuel rockets with exaggeratedly large fins, two of which were swung forward on pivots at the height of the flight, transforming the rocket into a glider. These winged rockets performed very well in quiet weather, but were erratic in wind.

Another Tiling suggestion, which he apparently never translated into actual practice, was to swing all of the fins forward as a group at the height of the flight. By a suitable system of pivots, they could then be made to act somewhat like the rotor blades of an autogyro, bringing the rocket down with a spinning motion. Such "spinners" have often been included in plans for experimental rockets, but are difficult to construct.

Long-range trajectory rockets intended to carry payload will almost certainly have to be supplied with some sort of controllable landing gear, probably retractable wings. Folded into the body at the takeoff and extended when the descent begins, such wings would act greatly to lengthen the flight. Equipped with ailerons or movable flaps, they could be used to steer the rocket, and thus guide it to the landing berth, either by remote control or by pre-set internal control mechanisms.

The landing problem, like all the others connected with rockets, contains no insurmountable difficulties, but is nevertheless far from being suitably developed. The spinner, the retractable wing and the parachute all offer quite suitable solutions, but better methods will no doubt appear as trajectory rockets are developed for long-range flight.

Chapter VI

Saltpeter's Child

I.

THE stimulation, inspiration—possibly the desperation—that led to the first recorded use of rocket power in war, seven centuries ago, we may owe to Ogdai, the son of Ghengis Khan, scourge of the East and conqueror of northern China.

For when Ogdai and his armies, marching southward to conquer the rich Honan Province of China in 1232 A.D., came to the ancient city of Kaifeng, capital of the province, they found the defenders there had two new secret weapons. The first was an explosive bomb, called in the Chinese *tchin-tien-lui*, or "heaven-shaking thunder." The second was *huo-chien*, "arrow of flying fire," which, upon being ignited, was able to fly by itself.

It is possible that this self-propelling "arrow" was the ancestor of all the skyrockets, war rockets, signal rockets, lifesaving rockets, and possibly moon rockets of the world. It does not follow that the Chinese were necessarily the inventors of it, however, for the city of Kaifeng at that time was not actually in Chinese hands: it was the temporary capital of the treacherous Chin (or "golden") Tartars, who had taken it away from the weak Chinese Sung dynasty a few years earlier. Whether therefore it was the Chinese, or the far-less favored race of the Tartars who discovered rockets may never be known.

Most historians presume that it was the Chinese, and that the event occurred about the beginning of the thirteenth century. There appears to be some evidence, however, that gunpowder was known to the ancient Byzantine Greeks, and rockets as well —and some maintain that the Chinese obtained the secret from the Byzantine Empire. If the Chinese were the inventors, word about rockets spread across the earth with what was, for those times, most amazing speed. Only eight years after the fall of Kaifeng, an Arab who enjoyed the full and rolling name of Abu

Mohammed Abdallah Ben Ahmad Almaliqi, but who was also called Ibn Albaithar—the "son of the horse doctor"—wrote a book in which he gave a complete description of saltpeter, the oxygen-producing ingredient of gunpowder and rocket powder. He referred to it as "snow from China."

About 1280—that is, only 48 years after the battle of Kaifeng—another Arab, one Hassan Alrammah, produced a book containing complete recipes for mixing gunpowder, and directions for making rockets. The latter he referred to as *alsichem alkhatai*, or "Chinese arrows."

Rockets quickly became more or less standard weapons of war throughout the East and Middle East. In Europe an otherwise unknown writer named Marcus Graecus produced a book on fireworks and combustibles, the *Liber Ignium*, or "Book of Fire." It was written in Latin, the language of scholars and scientists. A copy came into the hands of Roger Bacon in England around 1240. Another reached the writing table of Albertus Magnus in Germany a short time later. Both of these men borrowed parts of it for their descriptions of powder and rockets, and both later were variously credited with gunpowder's invention.

2.

There is no way of knowing how the Chinese—or the Byzantine Greeks—or the Tartars, actually came to invent the rocket, or the self-combustible powder needed to propel it. Saltpeter, the significant ingredient, is rather common in China: it is by no means impossible that a pyrotechnic mixture might have been discovered completely by accident, just as primitive men discovered accidentally how to make fire or bake pottery.

But a more romantic theory is often repeated by lecturers and writers on rockets; a story which traces the ancestor of the propellant, and hence the Chinese rocket itself, back to the ancient Greeks and their famous "Greek fire."

Throughout Europe and the Middle East many inflammable mixtures of this kind were compounded in the early centuries of the Christian Era. They were used as a means of applying fire to arrows shot against enemy breastworks, movable siege fortifications, houses, and hostile ships at sea or in port. The mixtures varied widely in composition, containing tow, pitch,

turpentine, sulphur and charcoal and such additional items as the imagination of the user could devise. Sometimes they included naphtha, petroleum and incense. The Greeks added another ingredient, common salt, which made the flame burn brighter and yellower, and therefore—as they thought—hotter.

In a day when fire arrows were an important part of the material of every army, any recipe for a hotter or more persistent fire mixture was a thing to be prized. So when the Chinese heard about the Greek version of wildfire, probably from one of the occasional travelers to their land, they promptly set out to make something just like it.

China's interior is a long way to the sea. Common salt is scarce there, but saltpeter, which in appearance and taste is not unlike salt if not examined too closely, was easy to obtain. So—as the

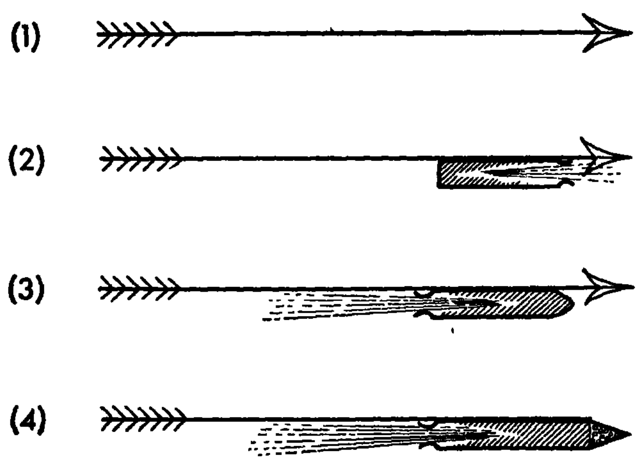


FIG. 12. Evolution of the skyrocket. (1) Ordinary arrow, (2) fire arrow, (3) self-propelling arrow, (4) skyrocket.

story goes—some ancient unknown experimenter by accident or design substituted saltpeter for salt in the Greek fire—and thus produced a genuine pyrotechnic fuel; the first artificial mixture ever to furnish oxygen for its own combustion.

It would be interesting to learn what that pioneer Chinese fire bowman may have had to say when his arrow, shooting out a stream of fire in front, hissed, and came blazing back at him. This unexpected phenomenon would surely have been puzzling! The early rocketor, of course, would simply have to turn the firecase around, making the thrust of the rudimentary rocket

motor correspond with the desired direction of the flight—and he could then dispense with the bow.

Another often repeated tale of those early days concerns a long-forgotten Chinese mandarin named Wan-Hu, reported to have been the first person to undertake flight by rocket power. About the year 1500, Wan-Hu, eager to get somewhere other than the place where he was, fastened two large kites and forty-seven big rockets to a sedan chair, strapped himself into the contrivance and when the kites were well aloft, commanded forty-seven coolies to light the rockets.

If this happened as described, the mandarin Wan-Hu had the distinction not only of being the inventor of the first passenger-carrying rocket, but also of being the first experimenter destroyed by his own rockets. For, in the usual version of the story, when Wan-Hu mounted the contrivance, fastened himself into the seat and gave the signal, the rockets exploded—and Wan-Hu hasn't been heard from, personally, since.

3.

The early haphazard powder mixtures of the Chinese and Arabs were probably what pyrotechnists call "lazy." That is, they contained an excess of charcoal or sulphur, and hence burned rather slowly. They were good for driving rockets; poor or useless for bombs or guns.

Around the year 1250 Roger Bacon disclosed to Europeans the true and proper method of mixing sulphur, saltpeter and the fine charcoal of hazelnut wood to "provoke thunder and destruction," and the gunpowder age was born. In his *Liber Ignium*, Marcus Graecus recommended that the powder be mixed in the proportions: one part charcoal, two parts of sulphur and six parts of saltpeter. Roger Bacon suggested a leaner mixture, consisting of saltpeter 41.2 per cent, sulphur 29.4 per cent and charcoal 29.4 per cent. Modern practice is to make it saltpeter 75 per cent, sulphur 10 per cent and charcoal 15 per cent.

The two early recipes would have produced a fairly good gunpowder; quite adequate in fact, to charge the crude guns which presently began to appear through Europe. In those days guns were used primarily to scare the enemy; it was a lucky hit indeed that did any damage. So poor was the accuracy of the

old smoothbore guns and so short their range that the rocket for centuries was considered at least as good a military weapon and maybe better. Not only could it make smoke and noise, but it could also carry incendiary charges, and thus set fires as well as frighten cavalry.

There are many records of rockets in fourteenth century wars and later. In 1379, during one of the innumerable Italian conflicts of that period, a tower in the town of Chiozza was set afire by rockets. By 1405 at least three kinds of rockets were discerned by contemporary writers: flying rockets, swimming rockets intended for naval warfare, and rockets that ran on strings. An Italian engineer, Joanes de Fontana, described rockets that looked like pigeons when in flight; rockets that ran along the ground "in the way of rabbits," and a large wagon running on rollers, propelled by three rockets. Fontana also told of a wooden rocket torpedo, shaped and painted to resemble the head of a sea monster to fool and confuse the enemy.

By the year 1500 virtually all of the "modern" forms of dry-fuel rockets had been developed and were widely used, both in warfare and for celebrations. Even pirates had adopted the rocket as a weapon by 1600 and German writers were complaining of the situation. In 1668, near Berlin, one Cristof Friederich Geissler introduced a very modern note indeed by shooting off some rockets that weighed 120 pounds each. Geissler was not just indulging in showy fireworks experiments, but was trying to develop rocket artillery that would have put to shame any cannon of his day. The payloads of his 120-pound rockets were slow-burning incendiary bombs.

By the middle of the eighteenth century the art of making rockets had become highly developed and something of a ritual. Several books were published on the subject, one of the most complete being *Artificial Fireworks*, written by Captain Robert Jones and published in 1774.

Captain Jones gave elaborate recipes for making rocket powder, the proportions varying with the weight of the rockets to be constructed. He declared that the best rocket cases are exactly six and a half times as long as their exterior diameter. He recommended that cases for the smaller rockets, from four ounces to six pounds, be made of the strongest cartridge paper,

rolled dry. For larger rockets, he suggested pasted pasteboard, rolled when wet and then allowed to dry thoroughly before charging with powder.

The choke or nozzle is to be made by binding the neck of the case, while the paper is still wet, with a piece of small twine, which must not be tied in a knot, but fastened with two or three hitches. The pinching or choking is to be done over a small "pinching tool," which adjusts the diameter of the nozzle to one-third the diameter of the rocket case.

The charging of the powder into the case Captain Jones described as the most ticklish and important part of the job. For this the rocket maker inserts the empty case in a charging mold of brass, which supports and enables it to withstand pressure. Through the nozzle hole at the lower end extends a cone-shaped tool or dibble, the "piercer," which is to form the combustion chamber in the powder. In addition, the rocket maker requires three ramming tools or "drifts" made of brass or copper.

The powder is put in carefully, a small ladleful at a time. After each scoop, the mold is shaken to settle the powder. The appropriate drift is inserted, "seated" with a wooden mallet, and then struck a number of times with firm, even blows, to compact the powder into a hard, flame-impervious cake.

Each scoopful of powder must be struck exactly the same number of times as the preceding ones. Otherwise the charge will burn at an uneven rate, and the rocket will be erratic in flight. For a four-ounce rocket, each ladle of powder should receive 16 strokes, according to Captain Jones. For a one-pound rocket, 28 strokes are required. A two-pounder requires 36 strokes per ladle; a four-pounder 42, and a six-pounder 56.

"Larger rockets," remarks the authority, "cannot be drove well by hand, but must be rammed with a machine made in the same manner as those driving piles."[1]

As to incendiary mixtures, often shot by rockets into enemy fortifications or ships, recipes were both complicated and ingenious. One John White, who appears to have been a collector of such matters, presents the following example in his *A Rich Cabinet of Modern Curiosities*, published about 1653:

[1] Later fireworks makers, and the military rocket manufacturers of the nineteenth century, used hydraulic presses.

Rock water (petroleum)	1 part
Peter in meal	1 part
Sulphur mealed	2 parts
Rosin	3 parts
Turpentine	1 part
Linseed Oil	1 part
Verdegrease	½ part
Bole-armoniack	½ part
Bay salt	½ part
Arsenic ("if you think fitting")	½ part

The author rather favored this mixture not only for rockets, but also for incendiary javelins, and he spoke very highly of the destruction that could be produced with it.

4.

Despite the ingenuity of these early investigators, the great day of the military rocket was still to come: the day when almost every military establishment in Europe was to have its rocket brigade; when the principal inventor of war rockets in England was to become so famous that manufacturers were to name their products after him, when titles and military rank were to be his just rewards.

All this occurred in the first half of the nineteenth century. The war rockets of those days are all but forgotten now, but they are nevertheless honored for all time by being included in the "Star-spangled Banner," in the line that goes "by the rockets' red glare, the bombs bursting in air. . . ." It happened that while Francis Scott Key was writing the song that was to become our national anthem, the British were bombarding Fort McHenry with war rockets. To the writers of that day, rockets and bombs were synonymous—and they had no reference to fireworks.

The story of the great military rocket period of the nineteenth century really begins in India, in the British campaigns that culminated with the siege assault and occupation of Seringapatam, the former capital of the state of Mysore, India, in 1799.

At that time rockets were still used in various armies of the East, and the princes of India were sometimes able to make telling effects with them. Haidas Ali, prince of Mysore before the

British conquest, had as many as 1,200 rocket throwers in his army. His son, Tipu Sahib, who was killed in the siege of Seringapatam, increased the number to 5,000.

The Indian rockets were made of iron tubes, weighed six to twelve pounds each, and were guided by long poles of bamboo. Spectacular use of them at Seringapatam profoundly affected public thinking in England and throughout Europe. It particularly interested an ingenious and talented young man of twenty-seven, William Congreve, who was studying law and editing a political newspaper in London. He heard the stories of the Indian war rockets, noted that they were effective and had considerable range; and decided that if some scientific work were put into them they could be even further improved.

It happened that Congreve's father, Lieutenant General Sir William Congreve, was comptroller of the Royal Laboratory at Woolwich. With his aid, the younger Congreve began to study war rockets seriously. The work began about 1804. Congreve's first rockets had a range of about 600 yards. After many experiments this range was increased to 1,500 yards, and later to about 2,000 yards.

He hadn't long to wait for a chance to try them against an enemy, for at that time the British were having trouble with the French, and the wars against Napoleon were at their height. By 1805 Congreve had made such progress that he was ready to try his rockets in a naval attack against the French coastal city of Boulogne.

All preparations were made, but inclement weather prevented the first attack. An armistice interfered with a second attempt. The third and final attempt took place on the evening of Ocober 8, 1806. Eighteen small boats participated, and 200 rockets were discharged within about half an hour from a distance of half a mile. Part of the city was set afire, and the experiment was deemed a fair success; enough, at least, so that the British naval authorities were willing to give it further trial.

In 1807 the British attacked Copenhagen with rockets. From 25,000 to 40,000 rockets were fired. A great portion of the city was set afire and burned to the ground. From that time forward the whole world began to be rocket conscious. In 1813 it was Danzig's turn. Here, after two or three abortive first attempts,

the city was set ablaze in so many places that the food stores were forced to close, and the garrison capitulated.

The British army became interested too, and in 1812 the first British Field Rocket Brigade was formed. After a year of training it was sent to join the allies against Napoleon in the Battle of Leipzig. The brigade's rockets were provided with bursting charges, and included both incendiaries and fragmentation shells. The latter, upon exploding, hurled a double handful of iron or lead pellets.

The Rocket Brigade took part in virtually every subsequent battle against Napoleon. Other countries took note; by 1830 there were rocket brigades in almost all of the major armies of Europe. The British continued to improve the Congreve rocket, and Congreve himself was rewarded with honors and titles. In 1810 he became equerry to the Prince Regent. In the following year he was elected a fellow of the Royal Society, a very considerable scientific honor. In 1811 he received military rank, becoming a lieutenant colonel in the Hanoverian artillery.

In 1812 he was elected a Member of Parliament, and in 1814, upon the death of his father, he succeeded to the baronetcy, becoming Sir William Congreve. By that time he had already embarked upon a series of scientific and engineering labors in fields other than rocketry. He was apparently the first man to urge the use of armor plate on naval ships. In 1813, at the request of the Admiralty, he designed a new gun for frigates. He also invented a gun mount for taking up the recoil, a parachute attachment for rockets, a method of printing—and not least—a perpetual-motion machine! So great was his fame that the first friction matches made in England were named after him.

Congreve's war rockets found their way into the "Star-spangled Banner" as a consequence of British activities on this side of the Atlantic in the War of 1812. Rockets were first used against the American army at the Battle of Bladensburg in August, 1914. Lieutenant Colonel Calvin H. Goddard, of the Historical Division of the United States Army Ordnance, writing about this battle in *Army Ordnance* in 1939, declared: "A flight of these ungainly projectiles directed against Stansbury's brigade had caused the regiments of Schults and Ragan to break and flee in wild disorder. As a result, the American flank was turned . . . and the day lost. Thus we may indirectly (or per-

haps directly) thank Congreve and his invention for the capture and burning of Washington which followed."

It was a month later, when the British navy was trying to repeat the Bladensburg success and visit the same destruction on Baltimore, that Fort McHenry was bombarded with rockets. Rockets were also used by the British against the American army at the Battle of New Orleans.

The Congreve rockets varied in weight from 13 to 42 pounds, and in range from 2,500 to 3,000 yards. By 1817 they were being made in at least seven different sizes and types, and an additional type of Congreve rocket equipped with parachutes was being used to send flares aloft. The rockets were encased in steel carcasses, and could be shot from light copper launching tubes or ladderlike racks.

For all the improvements he had made, however, Congreve was unable to find any better way of stabilizing the flight than to use guidesticks, which on some of his rockets were fifteen feet long. The accuracy was lamentably bad. In some instances, Congreve rockets actually returned to the ships which fired them, adding an extra item of excitement to the usual hazards of war.

At the time of Congreve's death in 1828, the war rocket of the nineteenth century had reached its zenith. The weapon was further improved by William Hale, who around 1850 found a way to increase the stability and get rid of the stick. This he accomplished with three small curved vanes in the path of the jet, which caused the rocket to spin rapidly in flight. This idea was adapted, of course, from the rifled artillery shell.

Hale rockets were used for several years in the dwindling rocket brigades of Europe, but rifling so much improved artillery that the war rocket steadily lost out. By 1900 it was obsolete.

5.

The final triumph of the rocket makers of the nineteenth century was not a rocket to take life, but one to save it. The line-carrying rocket, which appeared almost simultaneously with the Congreve war rocket, has been credited with saving more lives along rocky coastlines and in midsea rescues than any other single agency until the invention of radio.

Just who invented the line-carrying rocket is somewhat in doubt. In 1802 Claude Ruggieri, member of a famous family of fireworks makers who had migrated to France from Italy, wrote that his father had first suggested rockets for this use. Claude himself was one of the first experimenters to shoot "passengers" by rocket. He shot several small animals across the Mars Field, near Paris, one of them a sheep. He was prevented from launching a human passenger by the intervention of the police.

Both the Continent and England had claimants for the honor of making the first practical demonstration of line-carrying rockets. In Germany it was Ehrgott Friedrich Schaefer, a master weaver living in Prussia. In England it was a Cornishman, Henry Trengrouse, of Helston, Cornwall, who shot a number of small rockets about 1807 across the bay at Porthleaven to show that they could be made to carry a line over a foundering ship.

A rival apparatus, the Manby lifesaving mortar—invented by George William Manby, a royal military inspector—delayed the adoption of the Trengrouse system for several years. The Manby mortar shot a ball, to which the line was attached. Though this equipment had better accuracy than the rocket, it had the disadvantage that neither sender nor receiver could see it in flight except under good conditions; hence many lines were lost. The rocket overcame this trouble by making a trail of smoke in the daytime and a trail of fire at night. The aim could be corrected in subsequent shots, or the line recovered.

Rocket stations for livesaving were first opened in Great Britain on the Isle of Wight, in 1826, three of them being established that year by John Dennet, of Newport, who took out the first British patent on line-carrying rockets. In 1855, when the lifesaving rocket had been further improved, rocket stations were made official, and were credited with saving from 12,000 to 15,000 lives on the coast of England alone.

6.

The war rocket has had its ups and downs, but the skyrocket has persisted throughout the years. Today it is little changed in essentials from what it has been for several centuries.

It needs no great perception to conclude that the skyrocket, and fireworks in general, were originally derived from war

rockets.The Chinese who appear to have been the first to use them for celebrations as well as for combat, continued to this day to brand the skyrocket with the mark of its ancestor, the fire arrow. Native Chinese skyrockets wear feathers on their guidesticks, or slips of paper simulating feathers. The Chinese name (*huo-chien*) and their character for rockets is also still the same for skyrockets as for the fire arrow.

War rockets, however, are not fireworks: sparks, fire and color are required to please the artistic taste of pyrotechnic experts, and it was not the Chinese but the Italians who developed skyrockets to the state of brilliance and splendor we now associate with fireworks displays.

Fig. 13. The Chinese character for rocket, also for fire-arrow.

In the Middle Ages in southern Europe the making of fireworks was principally a family pursuit. Each clan of experts fashioned its own secrets. Metallurgy was in a crude state. There was no such thing as chemistry. The fireworks makers simply mixed ingredient after ingredient with their powders, producing such effects as were possible with these crude materials.

In addition, the Italian school of fireworks makers added extravagant arrangements and sequences as were suggested by their lively imaginations. By the seventeenth and eighteenth centuries Italian fireworks displays were world-famous.

Among the most successful was the family firm of Ruggieri, originally of Bologna. Members of this family traveled over most of Europe in the early part of the eighteenth century. One of their patrons was Louis XV, of France, who brought them to Paris for fireworks at Versailles.

In celebration of the Peace of Aix-la-Chapelle (October 7, 1748) some of the Ruggieris visited London at the request of King George II. In St. James's Park, on April 27, 1749, they put on a fireworks display which, for lavishness, has probably never been surpassed. Gaetano Ruggieri was the principal representative of the firm on that occasion, assisted by Giuseppe Sarti. So spectacular was the firework that the Board of Ordnance authorized the publication of a special book describing it.

The fireworks "machine" was situated 500 feet from the King's library. It represented a magnificent Doric temple, 410 feet long

and 114 feet high, with ornaments in relief, statues, colored paintings and transparencies. The fireworks started with a "grand overture of warlike instruments composed by Mr. Handel," followed by an opening salute of 101 brass ordnance. There followed 12 complete acts of fireworks, each more brilliant and elaborate than the last. The first consisted of "120 large honorary rockets, 96 smaller rockets in two flights, 12 mortars with air balloons and 12 caduceus rockets." Subsequent acts not only used more and larger rockets, but interspersed them with gerbs, fountains, fire pots and other set pieces. The last act ended with "a grand Girandole from the top of the Machine, consisting of 6,000 rockets headed with stars, rains and serpents."

All told the Ruggieris fired 10,650 rockets of all sizes on this occasion, varying in weight from ¼ pound to 6 pounds. They set them off with more than 12,000 fire pots, more than 1,000 "air balloons," cascades, "fixed and vertical suns," tourbillions, fountains and gerbs, and some 3,700 "lavas" and 5,000 "marrons."

So enormous was the effect of all this that fireworks thereafter became a regular part of all sports affairs in England. Bowling greens, tea gardens and seaside resorts were forced to add regular fireworks among their attractions in order to draw trade. Fireworks making became a local industry.

In their travels the Italian fireworks experts carried with them their word *rocchetta*, a word which originally meant a small distaff or spindle—also a dragonfly. The Germans accepted the Italian word, making it *Rakete*; the Russians picked it up, pronouncing it substantially in the German way. In Swedish the word became *racket*, in English, *rocket*.

The French, however, held to their own word *fusée*. To the Spaniard it is neither *rocchetta*, *rocket* or *fusée*, but *cohete*. This is also the name by which the rocket is known in South America, except in Brazil where the Portuguese equivalent, *foguete* is used. In Arabic, the word in transliteration is *sarukh* or *sawarikh*; in Turkish it is *fizek* or *fizenk*. The Dutch, like the Chinese, still call the rocket a fire arrow; their word is *vuurpijl*.

The later development of fireworks rockets, like the military rocket, passed through a number of phases, as knowledge of explosives and combustibles improved. Though earlier fireworks were greenish, reddish, and occasionally very brilliant, true color effects, like those now common in fireworks displays, began to

appear only about the beginning of the nineteenth century, when potassium chlorate was introduced into the pyrotechnic powders instead of the familiar saltpeter. Chlorate produces a quicker acting, hotter flame, and makes it possible to introduce metals effectively.

Among the earliest of the metal powders used in this way was magnesium, which gives an extremely brilliant white light, as any photographer knows who has used old-fashioned flashlight powder. Soldiers know the fire of magnesium, too; it is a common ingredient of star shells and incendiary bombs. Aluminum powder likewise is used in fireworks to produce intense white fire; it provides even more brilliant effects than magnesium.

Colored fire is produced by a variety of metallic salts. Red, the favorite, is provided by mixing salts of strontium, particularly the carbonate, with pyrotechnic powder. Blue is the product of salts of copper, such as the carbonate or sulphide, mixed with calomel. Green is made with the carbonate, chlorate or nitrate of barium. The carbonate of sodium burns with a bright yellow color.

Many of the best fireworks firms still have secret mixtures which are passed along from craftsman to craftsman. Among the secret ingredients are the "binders" and "brighteners" used to increase the mass of the flame or sparks, and to hold the various powder mixtures together during storage and shipment. The binders include shellac, pitch, paraffin, cornstarch, linseed oil and other materials. When "fountains" or gerbs are charged, iron filings or steel filings are mixed with the powder, to produce the brilliant and amazing sparks these set pieces give out. Lampblack mixed with the powder produces sparks of unusual forms, called "spur fire." Many skyrocket propellants contain these ingredients also, to increase the sparks and brilliancy of the fiery trail.

Chapter VII

The Persistent Man

1.

AFTER Congreve, the rocket had to make a new start. The start was supplied by Dr. Robert Hutchings Goddard, a young American physicist of Worcester, Mass.

A native New Englander, Dr. Goddard was a slender, quiet young man; early bald, careful of words and precise in thinking. He has always disliked publicity, and to this day he is almost unknown as a person, though famous for his work. His correspondence with fellow rocket experimenters has been a series of firm, crisp, disappointing negatives. He declines to enter into any of the lengthy discussions by mail which other experimenters and enthusiasts enjoy so greatly. When asked for word of his current work, it is his custom to say that it has not yet progressed sufficiently to justify a report.

Yet more than anyone else this steadfast, inventive and intuitive man has been responsible for the world-wide renaissance of the rocket in our time. Goddard is the true father of modern dry-fuel and liquid-fuel rocketry.

Born in Worcester on October 5, 1882, his early schooling and his college work were all obtained at Boston, where he lived until he was sixteen, and at Worcester, where he was graduated from the Worcester Polytechnic Institute in 1908. His academic career was conventional, rising in the usual steps from fellowship to instructor to assistant professor and finally to full professor at Clark University. His only "foreign" adventure was to accept a research fellowship at Princeton, in 1912, the year following completion of his work for the degree of Doctor of Philosophy at Clark.

In his school days he was a serious young man, with an odd streak of scientific speculativeness in his nature. He enjoyed mathematics, was fond of figuring out faster ways to travel, and

better ways to do things in general. In his freshman year at college one of his professors assigned the topic "Traveling in 1950" as a theme subject. Goddard produced a bold paper which he read before the class, describing in some detail a railway line in which the cars were supported electromagnetically without any metal-to-metal contact, in a tube from which the air had been exhausted. With such a vacuum railroad he calculated it would be perfectly possible to make enormous velocities safely; for example, a running time of ten minutes from Boston to New York.

Ten years later, when the French inventor Emile Bachelet proposed a similar plan for an electromagnetic railway, the editor of the *Journal* of the Worcester Polytechnic Institute remembered Goddard and wrote him for comment. Goddard not only produced a thorough mathematical critique of Bachelet's "frictionless railway," but sent along a short story based on the theme, which he had written about 1906.

As a young professor of physics, Goddard made contributions of importance on the conduction of electricity in powders, the development of crystal rectifiers, the balancing of airplanes, and the production of gases by electrical discharges in vacuum tubes. During his fellowship at Princeton, he produced the first laboratory demonstration of mechanical force from a "displacement current" in a magnetic field; this current being the fundamental concept in Maxwell's theory of electromagnetic waves (radio). These exploits however were merely by-products and tune-ups. His real love, after he had been led into it by curiosity about the upper stratosphere, was rockets and jet propulsion.

Goddard comes of an old New England family; one of his ancestors was Captain Levi Pease, who operated an early stagecoach line between Boston and New York. His father was in the business of manufacturing power-driven knives of the sort used in cutting paper and wood. The whole Goddard family was interested in transportation and mechanics: he grew up in an atmosphere of machinery and engineering accomplishment.

He doesn't remember exactly when he made his first experiments with rockets, but recalls quite vividly carrying on some static tests with small rockets in 1908, in the basement of Worcester Tech. He promptly filled the whole place with smoke, and had to talk fast to get out of trouble. While at Princeton

in the season of 1912-1913 he made the computations that formed the basis of his Smithsonian paper of 1919. It was in this period, when about thirty, that the great excitement of discovery first began to come to him. The calculations showed that only a little fuel, relatively, would be needed to lift a payload to really great heights by rocket. The theory, in fact, was so promising he could hardly wait to begin transforming his figures into actuality.

Upon returning to Clark in 1914 he began experimenting with ship rockets, which he purchased out of his slender salary as an instructor. Next came tests with steel rockets using smokeless powder, fired both in air and in a vacuum. Connection to a vacuum pump required the installing of extensive piping in the basement workroom at Clark. On one occasion Dr. A. G. Webster, head of the physics department, viewed the pipe system with an admiring eye. "Well, Robert," he exclaimed, "when you go I hope you leave all this tubing here!"

In the course of these experiments, Goddard spent some eight hundred dollars of his own money, and by 1916 had reached the limit of what he thought he could do on his own resources. Being inexperienced in the ways of self-promotion, he could think of no way to obtain a backer except to make out a report of what he had done with rockets, and project what he thought could finally be accomplished. With characteristic thoroughness, he cast the paper into the best scientific form, rewriting it several times. To complete the job he bound it in a special cover with a neat gold border, and sent it away to one foundation after another, hoping for support.

The Smithsonian Institution was almost the last address on his list. After filing away the collection of polite refusals he had received from the others, it was with some hesitation he sent the document forth once again. This time, after an interval of about three weeks, he received a letter from Dr. Charles D. Walcott, then secretary of the Smithsonian, commending him on his report,[1] and asking how much would be needed to continue the work. Goddard debated between asking a safe $2,500, which he felt would be inadequate, and $10,000, which perhaps would be enough but might be refused. Finally he compromised on $5,000—and by return mail received a warm letter granting his

[1] Though the report is dated May 26, 1919, it was not actually released to the public until January, 1920.

request. Folded with the letter was an advance of $1,000: the largest check he had ever seen.

Then began the series of experiments which were to launch modern rocketry and gain Goddard world-wide prominence. Almost nobody except those immediately engaged knew what these experiments were until the first Monday morning in January, 1920, when the Smithsonian Institution issued a news release on the work and simultaneously published the Worcester scientist's first paper on rockets: a modest sixty-nine-page monograph bound in brown paper, entitled "A Method of Reaching Extreme Altitudes." It was issued as a part of the Smithsonian Miscellaneous Collections, Volume 71, No. 2. Exactly 1,750 copies were published. This classical treatise, which marked the beginning of an era, is now out of print. Since the war it has become such a collector's item that even photostatic copies are quoted by booksellers at $35 each.

The Smithsonian paper was basically the same report as that submitted to the Institution in 1916. Goddard's experiments simply corroborated his earlier conclusions; only the factual data based on his post-1916 tests needed revision. As to the cost of the work, it had come to something over $11,000. Beginning with the original $5,000, the Smithsonian had put up all of it.

2.

Goddard divided his initial paper into three parts, dealing respectively with the theory of rockets, the experiments he made before 1919 (some of them at Worcester Polytechnic Institute and the others at Mount Wilson Observatory during the first World War[2]) and the calculations derived from theory and experiment.

[2] After the entry of the United States into the war in 1917, Goddard volunteered his services and was set to the task of exploring the military possibilities of rockets. He succeeded in developing a trajectory rocket which fired intermittently, the charges being injected into the combustion chamber by a method similar to that of the repeating rifle. The rocket had five charges and was capable of carrying an iron weight which simulated a warhead. He also developed projectile rockets up to three inches in diameter, intended to be fired at tanks and military personnel from a launching tube held in the hands and steadied by two short rear legs; a device in many respects similar to the "bazooka" of World War II. These weapons were demonstrated at Aberdeen Proving Grounds on November 10, 1918, before representatives of the Signal Corps, the Air Corps, the

It is these calculations which are today the most interesting. Among other things he figured out the "initial masses" of a series of theoretical rockets which would be powerful enough to lift a payload of one pound to various heights in the atmosphere. Making some assumptions as to the jet velocities attainable, and the efficiency of his reaction motors, he concluded that to raise one final pound of rocket to a height of 35 miles would require a starting weight of only 3.66 pounds, provided an "effective velocity" of 7,000 feet per second could be obtained.

This "effective velocity" was a figure representing the performance of the rocket. Goddard assumed that it would not be impossible to attain an "effective velocity" of 7,000 feet per second, though today this proposition does not appear as simple as his early calculations made it seem.

To show what really great altitudes could be obtained with a relatively small starting weight, continuing to assume an "effective velocity" of 7,000 feet per second, he showed that an altitude of 71 miles would be reached with a total starting weight of 5.14 pounds; 115 miles with a starting weight of 6.40 pounds, and 437 miles with an initial mass of only 12.33 pounds.

Just in case these high "effective velocities" would not be forthcoming, Goddard also made calculations for an "effective velocity" of 3,500 feet per second, which he declared would allow of "considerable inefficiency in the rocket apparatus." The starting weights for the various altitudes now came out higher: 12.6 pounds for 35 miles, 24.36 pounds for 71 miles, 38.1 pounds for 115 miles, and 267.7 pounds for 437 miles. Even here, Goddard concluded, "the mass is sufficiently moderate to render the method perfectly practicable."

As a way to construct rockets with a suitable ratio of propellant to structure to permit of such high altitudes, Goddard went on to give a clear explanation of the theory of the step-rocket, a device upon which he had himself received the basic patent nearly six years earlier, on July 7, 1914. A step-rocket, of course, is a multiple rocket, in which the larger part is consumed, to give high velocity to the smaller part. Two, three or more rockets

---

Army Ordance and others. The demonstrations went off successfully, but the Armistice next day put an end to the war and also to the experiments. Goddard's data on these weapons have ever since been locked in the archives of the War Department at Washington.

may be joined together in this way and shot in series, each charge giving increased velocity to the portion that remains.

He also disclosed that he had put to rest the old fallacy that a rocket thrusts by "pushing against the air." He had shot rôcket motors in partial vacuum, and obtained results equal to or even better than at atmospheric pressure. Likewise, he had tackled the problem of constructing dry-fuel motors separate from the powder charge, and had developed successful intermittent motors in which the propellants were inserted by a device working on the general principle of the machine gun.

He ended the report with what was, for 1919, a startling conclusion: that in theory at least it should be perfectly possible to shoot a rocket at such velocity that it would not return to the earth. With a total launching weight of only eight or ten tons, he estimated, a rocket could be constructed capable of carrying enough magnesium powder to create a telescopically visible flash against the dark side of the moon.

It was this discussion of a possible moon-rocket, rather than the less spectacular but more practical work reflected by the rest of the book, that most forcefully reached the public. Newspaper readers across the continent were moved to excitement, comment and derision. The rocket came forth once more out of the history books and military museums and began to have the beginnings of a new world prominence—only this time with an ironic twist. During the period when for the first time it was really undergoing something like genuine scientific development, the rocket was to become, to many unthinking people, a symbol of impractical ideas and fantastic schemes. Everyone who had to do with rockets during the next two decades was to be branded as "queer"; and rocketors

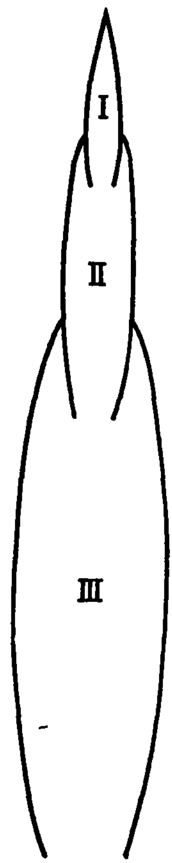


FIG. 14. Scheme of the step-rocket. Small rocket I is the payload of rocket II. Rockets I and II are the payload of rocket III. The largest rocket, III, is fired first. When its fuel is consumed, the empty rocket is jettisoned and rocket II is fired, etc.

were to inherit the mantle of ridicule previously worn by airplane pioneers.

3.

The publicity accompanying the release of Goddard's report made a stir abroad as well as in this country. In 1919 rocketry was completely dead in Europe, and had been since before the turn of the century. Unexpectedly in 1923 there appeared a highly technical little book printed in Munich at the author's own expense, called *Die Rakete zu den Planetenräumen*, or in English, "The Rocket into Interplanetary Space." The author was an unknown professor of Hermannstadt, Transylvania, named Hermann Oberth. His book bristled with technical language and obscurities.

Oberth had received a copy of Goddard's 1919 report directly from the author in late May or June of 1922, in response to a quaintly worded letter in English written from Heidelberg May 3 of that year.

> Dear Sir: [Oberth wrote Goddard]
>
> Already many years I work at the problem to pass over the atmosphere of our earth by means of a rocket. When I was now publishing the result of my examinations and calculations, I learned by the newspaper, that I am not alone in my inquiries and that you, dear Sir, have already done much important works at this sphere. In spite of my efforts, I did not succeed in getting your books about this object. Therefore I beg you, dear Sir, to let them have me. At once after coming out of my work I will be honored to send it to you, for I think that only by common work of the scholars of all nations can be solved this great problem.
>
> Yours very truly,
>
> Hermann Oberth, stud. math. Heidelberg.

Oberth's book set forth in greater detail than Goddard's report the theoretical background of possible interplanetary travel by means of rocket power, and touched off a great controversy. Technical men in high places, some of whom had apparently not even read the book, criticized and ridiculed it. Oberth also had his adherents; men of similar ideas began to write books in defense and explanation.

One of the volumes soon to follow was written by Dr. Walter

Hohmann, city architect of Essen-on-the-Ruhr. Its confounding title was *Die Erreichbarkeit der Himmelskörper*, or "The Attainability of the Celestial Bodies." He dealt, in a fashion even more bloodless and mathematical than Oberth, on the theoretical problems of departure from the earth, return to the earth, free coasting in space, circular orbits around other planets, and landing on the celestial bodies.

It was not until Max Valier, later to become famous as a spectacular experimenter with rockets and rocket cars, wrote his book, *Der Vorstoss in den Weltraum* ("A Dash into Space") late in 1924 that the subject began to come down out of the clouds and take on a semblance of something that ordinary people could understand. Valier's book discussed interplanetary flight in laymen's language. It still contained mathematical passages (written for him, it has been reported, by Oberth) but these could be skipped by the average reader without losing any of the sense of the argument.

In 1926, Willy Ley, a young man who was later to become one of the organizers of the *Verein für Raumschiffahrt* (the German Rocket Society), joined this battle of the books with a small volume of eighty-three pages, entitled *Die Fahrt ins Weltall* ("Traveling in Space"). In the ensuing five years many other German books appeared on rockets, rocketry and flight to interplanetary space. These included, besides the technical and popular books, a manuscript for a film entitled *Frau im Mond* ("The Girl in the Moon"), written by Thea von Harbau, then the wife of Fritz Lang, the motion-picture director. This later was turned into a popular movie and also a novel, and was to play a curious part in the story of rocketry in Germany. In France, at least one important book on rockets and interplanetary flight soon appeared: a small monograph by Robert Esnault-Pelterie, an aircraft engineer and manufacturer. It was later enlarged into a major book, *L'Astronautique*. In Russia, books on rocketry and interplanetary travel began coming from the presses as early as 1924.

But in terms of furtherance of the rocket, all this unfortunately meant very little. The Germans were too busy arguing the merits of space flight to do any actual experimenting. The British and French were entirely oblivious of the practical side of the matter. The Russians were making some preliminary

moves toward experimentation, but had not begun to do anything. In the meantime Goddard was going doggedly ahead, making and shooting rockets.

After the publication of "A Method of Reaching Extreme Altitudes," which dealt so optimistically with dry-fuel propellants, Goddard came to the conclusion that despite the convenience of these fuels they could not bring about the results he had in mind. Accordingly he gave them up and turned his attention to the problems of developing liquid-fuel rockets.

From 1920 until 1922 he made what are now known as proving stand tests with liquid-fuel motors, trying liquid oxygen and various liquid hydrocarbons, including gasoline, liquefied propane and ether. He presently decided that liquid oxygen and gasoline made the most practical combination; virtually all of his subsequent liquid-fuel experiments were carried out with these liquids.

By 1923—the year Oberth's book appeared in Europe—Goddard had reached the point of trying an actual shot with a liquid-fuel rocket. Still working with funds supplied by the Smithsonian Institution, he constructed a small rocket in which the fuels were fed to the motor through pumps. This contrivance was tried on the proving stand, but was not released for flight. Two years of further experiment followed, culminating in the production of a second gasoline and liquid-oxygen rocket. This one dispensed with pumps and made use of nitrogen gas under pressure to force the propellants into the combustion chamber. Like its predecessor, it was not considered good enough to release for actual flight.

A year later Goddard finished his third liquid-fuel rocket, and on March 16, 1926, let it fly. This was the first actual shot of a liquid-fuel rocket anywhere in the world. It occurred at Auburn, Massachusetts, on a cold, clear spring day. There was snow on the ground, a couple of inches or so. The experimenter and his assistants were heavily bundled up: Goddard in a huge double-breasted overcoat and a flat cloth cap. Though his associates wore their gloves, he went barehanded, his gloves crammed into the bulging pocket of his coat.

The only witnesses to that historic flight other than Dr. Goddard himself were Henry Sachs, machinist and instrument maker of the Clark University shop; Dr. P. M. Roope, assistant profes-

sor of physics at Clark (now head of the physics department), and Mrs. Goddard, who came along to take the pictures which later documented the report.

The rocket was an odd and fragile-looking contrivance. The motor, with its metal nozzle nearly as long as the cylindrical blast chamber, was mounted at the forward part of the rocket in a slender frame consisting of the fuel pipes, crossed by a bracing strut engaging the nozzle. A diagram of the rocket has not previously been published, but for this book Dr. Goddard has made available the drawing shown in FIG. 15. The whole rocket was about ten feet tall; the motor measured over all about two feet, and fuel tanks were about two and a half feet long. The motor was thus separated from the rest of the rocket by an air gap of four or five feet, bridged by the thin metal tubing that conducted the propellants.

The purpose of this arrangement was to place the motor at the front, where Goddard then believed the thrust should be applied for the best stability in flight. The motor was ignited through a tube at the top, the ignition being supplied by an assistant equipped with a blowtorch on a six-foot pole. In pictures taken before the shot, the assistant is shown posing calmly with the blowtorch held at the ignition point. It is probable he was not quite so collected when the actual shot occurred, for the ignition period is a touchy moment in the launching of any rocket—if it is going to explode, it most likely will do so then.

Goddard's 1926 rocket did not explode. Instead, it took off with a loud roar, rose in a high trajectory, and flew for two and a half seconds, traveling a distance of 184 feet. Timing it with a stop watch, he calculated later that its average speed was 60 miles an hour.

This pioneer rocket was not, obviously, very well laid out for flight. The design was unnecessarily awkward because the motor had been placed at the front—an early error of almost all rocket experimenters.

The location of the motor with respect to the center of gravity of rockets is still a subject for some debate among experimenters, but Goddard, who has built many since that day in 1926, has delivered himself unequivocably on the subject:

> It will be seen that the combustion chamber and nozzle were located forward of the remainder of the rocket, to which

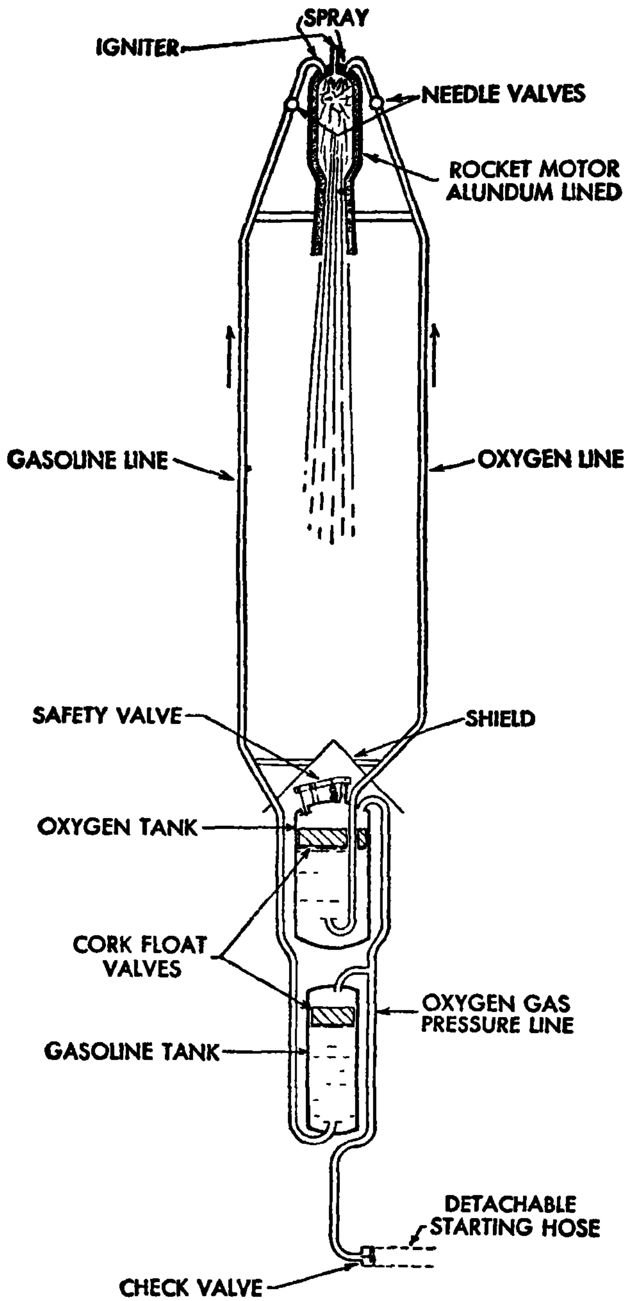


FIG. 15. Dr. Goddard's historic 1926 liquid-fuel rocket in cross section. Drawing by Dr. Goddard especially for this book.

> connection was made by two pipes. This plan was of advantage in keeping the flame away from the tanks, but was of no value in producing stabilization. This is evident from the fact that the propelling force lay along the axis of the rocket, and not in the direction in which it was intended the rocket should travel, the condition therefore being the same as that in which the chamber is in the rear of the rocket. The case is altogether different from pulling an object upward by a force which is constantly vertical, when stability depends merely on having the force applied above the center of gravity.[3]

The 1926 rocket had another feature of interest: the fuels were forced into the motor by oxygen gas pressure. The evaporation of the liquid oxygen, together with oxygen pressure gas supplied before starting, furnished pressure during the flight.

4.

Following this first shot, other short flights with liquid-fuel rockets were made at Auburn; all very quietly, with such elaborate secrecy that nobody but the experimenter and his immediate circle knew what was going on. But rocket experimentation is hard to keep a secret; the rocket itself is a mighty self-advertiser. On July 17, 1929, Goddard shot a rocket of some size, big enough to carry a small barometer and a camera. It made noise in proportion. Someone who witnessed the flight from a distance mistook the rocket for a burning airplane and notified the police and fire departments.

Goddard was on the front pages of the newspapers again the next day: for the first time, virtually, since the publication of his "A Method of Reaching Extreme Altitudes." This time the uses of publicity were to be proved to him in a most pleasant and exciting way. Colonel Charles A. Lindbergh, then at the height of his popularity, read about Goddard's experiments and became interested. He communicated his interest to Daniel Guggenheim, and the capitalist made a grant of funds to put Goddard's work on a considerably more adequate financial basis.

Goddard meanwhile had moved his experiments to more secluded quarters at Fort Devens, Massachusetts, on ground placed at his disposal by the United States Army. Here, though

[3] *Liquid Propellant Rocket Development* (Smithsonian Institution) 1936.

he was free from unwelcome visitors, the work was going slowly, principally because of the difficulties of transportation.

When word came of the Guggenheim grant, the first job was to select a suitable site for the experiments. He chose New Mexico, it being a country "of clear air, few storms, moderate winds and level terrain." The final decision fell upon the vicinity of Roswell, in the south, where there were good power and transportation facilities. The actual site was the Mescalero Ranch, where a shop was erected in September, 1930, large enough for himself and four assistants. A small tower 20 feet high was then built near the shop for static tests, equipped with heavy weights to keep the test rockets from rising out of the tower. A 60-foot launching tower previously used at Auburn and Fort Devens was put up about 15 miles away, for flight tests.

The first project was to develop a standard rocket motor which would deliver dependable power. The motor finally produced was 5¾ inches in diameter and weighed 5 pounds. Its maximum thrust was 289 pounds and it could burn 20 seconds or more. Goddard later stated that this motor produced the equivalent of 1,030 horsepower, or 206 horsepower per pound, the horsepower being calculated from the energy of motion of the blast, with the rocket held at rest.

On December 30, 1930, the first flight of a rocket at the New Mexico site took place. The rocket was 11 feet long, and weighed a little over 33 pounds. It reached an altitude of 2,000 feet, and a maximum speed of 500 miles an hour.

It was big, but it set no altitude record, for as Goddard later pointed out, his first objective was to produce a dependable rocket, not to see how high he could shoot. To this end he also began studying the problem of stabilizing the flight, for he had become convinced that it was impossible for a rocket to fly even straight up without some sort of controlling device.

The first flight of a gyroscopically controlled rocket was made on April 19, 1932. In this rocket the steering vanes were forced into the blast of the rocket motor by gas pressure—the pressure, and therefore the amount of steering, being controlled by a small gyroscope. The scheme showed some signs of working, but the test was hardly a complete success. Goddard concluded that the vanes used in the experimental model were too small.

5.

When the original Guggenheim grant was made, it had been agreed to undertake the work in New Mexico for two years; then study the results with a view to a two-year extension. To supervise things, a committee had been named, headed by Dr. John C. Merriam, then president of the Carnegie Institution, and including such other scientific figures as Dr. Charles G. Abbot, then secretary of the Smithsonian Institution, Dr. Walter S. Adams, director of the Mount Wilson Observatory, Dr. Robert H. Millikan, president of the California Institute of Technology, and Colonel Lindbergh.

This committee gravely studied Goddard's reports, and recommended the granting of funds for the two additional years. But the great depression was then on. Goddard went back to Clark University to resume his teaching. The Smithsonian Institution, loath to see the research come to an end, made a small grant to permit some laboratory tests that did not require rocket flights. In the following year the Daniel and Florence Guggenheim Foundation also came to the rescue, and work was resumed in New Mexico in 1934. Taking another leave from Clark University, Goddard went back to Roswell, swept out the shop, cleaned the lathes, fixed up the towers, and resumed his experiments.

The job, now, as he saw it, was to develop fully stabilized flight, by whatever would be the simplest and most effective means.

In the beginning he tried a device to which many an experimenter has given thought—a stabilizer operated by a pendulum. Some stabilization effect can be obtained by this means, but as the rocket's acceleration increases, the pendulum becomes less effective, because the direction of the pendulum is inevitably a resultant between the acceleration of gravity and the acceleration of the rocket.

Goddard's pendulum-controlled rocket rose about 1,000 feet, bellied over, flew horizontally for about two miles, and landed 11,000 feet from the launching tower. At one point the speed exceeded 700 miles an hour—or nearly the speed of sound.

Goddard next approached the stabilizer problem by returning to his first idea, a small gyroscope. With his gyro-control, a series of beautiful rocket shots were made, beginning March

8, 1935, when the gyro-rocket reached an altitude of 4,800 feet, flew a horizontal distance of 13,000 feet, and made a maximum speed of 550 miles an hour. The gyroscope was set to correct the flight when it deviated 10 degrees or more from the vertical. Since this permitted a considerable lag, especially at the beginning, the first few hundred feet of flight looked like a fish swimming gracefully upward into the air. As the rocket picked up speed, the oscillations became much smaller, then virtually disappeared. (See Plate XIV.)

The equipment was gradually improved. A notable gyro-controlled flight was made on October 14, 1935, when the rocket rose 4,000 feet. On May 31, 1935, a gyro-rocket reached an altitude of 7,500 feet, or nearly a mile and a half. As in the previous experiments, Goddard was not attempting to set altitude marks in these shots, but was still concentrating on the complicated task of developing the apparatus to a state of reliable performance. His gyro-rockets weighed from 58 to 85 pounds at starting, and some were 10 to 15 feet in length.

6.

Goddard concluded his latest report, in 1936, with the remark that the next step in the development of liquid-propellant rockets is the reduction of weight to a minimum, a natural prelude to high-altitude shots.

"Some progress along this line," he dryly remarked, "has already been made." The exact nature of this progress has not yet been disclosed, but it is known to have included the development of liquid-fuel pumps, which may make gas pressure unnecessary in future Goddard rockets.

In 1940, Goddard reported to Washington, along with many another rocket experimenter, for work on projects which understandably cannot now be described. Responding to a query from an officer of the American Rocket Society, of which he is of course a member, he recently declared that he has definite plans to continue his rocket research in New Mexico as soon as war conditions will permit. And this time he may be ready, at last, to set some altitude records.

Chapter VIII

Rooting of the Seed

1.

We have seen how the European interest in rocket power began as a battle of books, arguments and theories, with a motion picture and a novel thrown in for good measure. The first books were German, and came forth with overwhelming, heavy-sounding titles. Oberth's was *Die Rakete zu den Planetenräumen* ("The Rocket into Interplanetary Space"), followed by Dr. Hohmann's *Die Erreichbarkeit der Himmelskörper* ("The Attainability of the Celestial Bodies"). Max Valier's was third; its German title, *Der Vorstoss in den Weltraum* is translatable as "A Dash into Space." Willy Ley then wrote *Die Fahrt ins Weltall* ("Traveling in Space"), to be followed in a short time by *Die Möglichkeit der Weltraumfahrt* ("The Possibility of Space Traveling").

These were the vanguard. There were soon many others in German, French and Russian. Nikolai Rynin, an indefatigable technical encyclopedist, had begun work in Leningrad on a nine-volume collection on rockets and space traveling. Esnault-Pelterie, in France, was soon to make the lecture on space exploration which later grew into his book, *L'Astronautique.*

In 1928 this mountain of literature was still piling up, all devoted to the peculiar problem which was strangely occupying the European mind at the time—getting away from the earth. Few of these books presented what might be called engineering designs or programs. They were theoretical, mathematical, and written without much practical notion of how to build a rocket that would rise for a mile, let alone the 240,000 miles to the moon.

At that time, however, had you limited your reading to newspapers and magazines, you might well have imagined that it was in Europe that most of the great thinking and doing about

rockets was going on. Many people will tell you to this day that rocket experiment is essentially European in origin. Yet not until thirteen years after Goddard made his original research, and eight years after he had begun the liquid-fuel experiments which were to become classic in rocketry, did anything even remotely resembling practical experiment begin abroad. The beginning even then was primarily a publicity stunt: a "rocket-driven motorcar"—a palpably impractical idea considering the requirements for rocket motor efficiency. The author of it was Max Valier, a young German aviator of thirty-three who should have known better.

This Valier was a dashing fellow of many talents. Before the first World War he was an astronomer in Munich. During the war he became a flight officer in the Austrian army and acquired a small reputation as a daredevil by volunteering to test new airplanes and engines. On one occasion at this hazardous occupation he fell more than 4,000 feet in a burning plane, extricating himself at the last moment in true movie fashion and landing safely by parachute. Following the war he came in contact with the ideas of Oberth and Goddard, and then began to develop theories of his own about the possibilities of rocket power for aircraft.

Despite its undigested combination of technicalities and pure imagination, his book on space traveling sold very well and later justified revision, expansion and reissue under the title *Raketenfahrt* ("Rocket Flight"). Convinced by then that the rocket was something he could profitably hitch his personal wagon to, Valier approached Fritz von Opel, the German automobile manufacturer, with the idea of a rocket-driven automobile.

Opel himself cared nothing for the technicalities of rocket research, but he sensed a new way to add to the fame of his small cars and consented, provided Valier could obtain rockets immediately rather than undertake research to develop anything new. Valier promptly went to Friedrich Wilhelm Sander, a manufacturer of dry-fuel rockets, and enlisted his aid.

By mid-March of 1928 the Opel rocket car was ready for its first test. Two Sander rockets were attached; one of the type known as a "bored rocket," which had an internal combustion chamber somewhat like the conventional skyrocket; the other a slow-burning type known as a "brander," which had no inside chamber. The "bored" rocket was capable of delivering a thrust

of about 400 pounds for three seconds. The "brander" burned 30 seconds and produced a thrust of 45 pounds.

The secret test did not go very well. The rockets were unable to give the car much velocity from a standing start. However, on a subsequent trial the same day the Opel test driver, Kurt Volckhart, brought the car to a speed of 35 miles an hour with the engine, then shut off the motor and turned on the rockets. The car continued to gain speed, ending by going at about 45 miles an hour.

The first "official" trial was set for the next day. Newspaper reporters and magazine writers were called to witness it. A battery of 12 rockets was fastened to the car, and though some of them did not ignite, the car reached a speed of more than 70 miles an hour.

Opel was elated. He bought space in the major German magazines, advertising the "rocket car experiments." The Opel engineers quickly turned out spectacular plans for a rocket car to be known as the *Opel Rak II*, with stubby wings tilted downward to keep the speeding vehicle from taking to the air under its rocket power.

Opel Rak II had its first run on the Avus Speedway near Berlin, on May 23, 1928. Twenty-four rockets composed its power battery, and it reached a speed of 125 miles an hour. At its wheel was no mere test driver this time, it was Opel himself.

The publicity continued to be amazingly successful. Photographs appeared in newspapers all over the earth. Opel kept pressing for more. *Opel Rak III*, next in the series, was designed to exceed every speed record ever made by man. This rocket car was designed to run on rails. Arrangements were made to use a straight, level section between Burgwedel and Celle, near Hanover, for the experiment. A battery of ten large rockets furnished the driving power, and there was also a "braking battery" of rockets at the front, to stop the car at the end of its run.

The first test took place on June 23. Nobody rode the car; it was set to operate automatically. The driving rockets performed as expected, accelerating the car to nearly 180 miles an hour, but when the braking rockets were turned on, they merely shot away from the car. *Opel Rak III* went careening along the track for several miles, and had to be run down and hauled back for the second test.

This time, Opel insisted on a charge of 30 rockets; this was to be the record setter. All 30 rockets went off as expected, but the acceleration was so high the car jumped the track.

There were two more *Opel Raks*, respectively *IV* and *V*. *No. IV* suffered the same fate as *No. III*. *No. V* never had a chance to show what it might do. The authorities, considering this a dangerous and unfruitful sport at best, banned any further tests.

Opel then went in for rocket-driven gliders. Valier, still interested in cars, made a connection with another firm, that of Eisfeld of Silbermuhle. With this new backing he successively built a rocket-propelled railway car that lost its wheels when the rockets went off; a rocket-driven sled and an unsuccessful rocket-driven glider. Somewhat discouraged, he began to consider whether the trouble wasn't the enormous acceleration produced by the fast-burning dry-fuel rockets. His next venture was more nearly in the right direction; he resolved to experiment with liquid fuels.

This time the experiments were backed by Dr. Paul Heylandt, a manufacturer of liquid oxygen. Valier mounted a liquid-oxygen motor at the rear of a small automobile, and around the middle of April, 1930, he had brought the apparatus to a state where he felt ready to try it out. The result was disappointing. The motor smoked badly, had little power, and was able to push the car along only grudgingly.

The first Valier-Heylandt liquid-fuel motor was little more than a metal tube about eighteen inches in length, into which liquid oxygen and benzine were conducted by separate small pipes. It weighed seven pounds, and Valier announced that it "was capable of delivering about 40 horsepower." After improvements, Heylandt and Valier disclosed that its weight had been increased to 11 pounds, which "made it possible to attain a maximum output of 220 horsepower.[1]

Alas for these optimistic statements: on Saturday evening, May 17, 1930, Valier was working late in the empty Heylandt factory, giving his motor some last minute tinkering, when the apparatus exploded. A jagged sliver of metal cut the jugular vein in Valier's throat. He bled to death before help could arrive.

So far as technical achievements were concerned, Valier's work was of relatively little value. But it served a larger—and in

[1] Some photographs of this motor indicate that it may have been at least partly regenerative.

the long run possibly a more fruitful—end: it brought to the attention of the world the fact that rocket motors had power; that they might be put to practical use (though Valier's uses were not practical). It interested hundreds of young men all over the earth in the rocket as a possible career, and helped in several unexpected ways to lay the foundation for subsequent events.

Valier, with a series of projects of no scientific value whatsoever, was thus able to do for rocketry what the successful and penetrating work of earlier experimenters had not done; what even the landslide of technical and popular books on interplanetary flight in Germany and France had been unable to do. It brought rocketry down to earth, and gave rocket power the first semblance of appeal to practical men.

2.

At about this point, Thea von Harbau and her movie scenario *Frau im Mond* come into the story.

Fritz Lang at that time was not only the foremost motion-picture director in Germany, but a tremendously popular person as well. He convinced the UFA Film Company executives that *Frau im Mond* would make a great picture. When they agreed, one of his first acts was to call to Berlin the small, mystical, mathematical-minded author of *Die Rakete an den Planetenräumen*, Hermann Oberth.

Oberth was to serve as "technical adviser" for the film, and also build a real high-flying rocket, to be shot to great altitude just before the release of the picture. In short, Oberth's first contribution to rocket engineering was to be a publicity stunt, too.

Lost and bewildered in Berlin, the schoolmaster who had reasoned so penetratingly about flying into space found it difficult to get anything done here on the earth. With the assistance of two equally inexperienced helpers, Rudolf Nebel and Alexander Shershevsky, he set about it to design and build a high-altitude rocket powered by liquid fuels. He had only four or five months in which to accomplish this feat, but nevertheless commenced with some rather remote laboratory experiments, one of which consisted of squirting gasoline into a bowl of liquid air, to ob-

serve how it would burn. This test blew out the windows of the laboratory.

Oberth's next step was to design and construct a liquid-fuel motor; a cone-shaped affair he called a *Kegeldüse* (from the German word *Kegel*, a cone). In this contrivance he planned to burn liquid oxygen and liquefied methane (marsh gas). But after a long search, he found he could not get liquid methane in Berlin, so he turned to gasoline.

His projected high-altitude rocket was to be six feet long, about eight inches in diameter, torpedo-shaped, and made of aluminum alloy. The plan was to shoot it from the Baltic coast, and all the time Oberth was performing his elementary experiments and tinkering with his *Kegeldüse*, the publicity department of UFA was supplying the newspapers with fantastic accounts of what was to be expected of this rocket. It was to shoot 45 miles into the air. Arrangements were to be made to operate special trains for spectators from Berlin, Cologne and other points. Special bomb-proof shelters were to be erected for the shot.

The flight was postponed—and postponed again. Oberth, confronted with the necessity of finishing some kind of projectile in time for a shot in advance of the release of the picture, redesigned his rocket completely. It was now to consist of a tall container of liquid oxygen, in which were to be immersed some sticks of carbon. The carbon was to burn in the oxygen, and affairs were to be so arranged that the combustion of the carbon would exactly match the rate of combustion of the oxygen, thus keeping the liquid level with the top of the carbon sticks until both propellants were consumed.

This ingenious idea was doomed to failure. Oberth was unable to find any carbon that would behave as planned. The day drew near for the picture's release—and still no rocket. There was never to be any shot of this rocket, probably the most highly publicized such project ever undertaken. *Frau im Mond* had ultimately to reach the public without its aid.

When the futile publicity had died away, Oberth and Nobel, aided by Willy Ley and others, made an actual test of the *Kegeldüse* before an official of the *Chemisch Technische Reichsanstalt* (The German Institute for Chemistry and Technology). Reportedly it performed without mishap, on July 23, 1930, burn-

ing for 90 seconds, consuming 13 pounds of liquid oxygen and 2.2 pounds of gasoline, and providing a thrust of 15.5 pounds; corresponding to a jet velocity of about 3,000 feet per second.

That was Oberth's last experiment in Germany, at least for the period before the war. He went home to Transylvania, and resumed his teaching.

3.

The first working liquid-fuel rocket in Europe was, as a matter of fact, the product of none of the already well-known figures in rocketry, but was built quietly near Dessau, Germany, and shot without advance notice. The experimenter was Johannes Winkler, a former *Junker* engineer. The cost of experiment was met by Hugo A. Huckel, a German manufacturer.

Winkler's first rocket was a surprising item. It had three tripod-like legs, or tanks, carrying respectively liquid oxygen, liquefied methane, and nitrogen gas to pressure the fuel. The motor was mounted at the center of the tripod, pointing downward, and was nothing but a straight seamless tube of steel. To "streamline" the rocket, Winkler had covered the tripod legs with sheet aluminum, so that the contrivance resembled a sort of aluminum prism.

Ready to fire, it weighed eleven pounds, of which about three were fuel. The shot occurred on March 14, 1931, and thus Goddard's first liquid-fuel shot anticipated it by almost exactly five years. Winkler knew nothing of that, however, and ignited his strange rocket under the impression that it was literally the first working liquid-fuel rocket on earth. It rose about 1,000 feet, turned over on its side when the fuels ran out, and came down about 600 feet away.

Winkler immediately began work on another, larger rocket. This one was nearly seven feet tall, with a torpedo-shaped body somewhat similar to that projected by Oberth. It had large fins, and the body contained two spherical or slightly ovoid tanks for liquid oxygen and liquefied methane, respectively. The experimenter told reporters he expected it to reach an altitude of about 20,000 feet, and he also declared he had made calculations on a liquid-fuel rocket that could carry mail from Berlin to New York, with a probable consumption of 50 pounds of fuel for each pound of mail delivered.

The large rocket was ready for testing late in September, 1932. At the first attempt it refused to operate; something had happened to the valves. Winkler worked on it until October 6, then tried again. This time the rocket rose a few feet—accounts vary from 6 feet to about 50—and exploded violently. The fuel had somehow become mixed in the tanks.

4.

Winkler's was one of the last individual liquid-fuel rocket experiments in Europe. Already, by the time of his first shot, the members of the *Verein für Raumschiffahrt*—the name means "Society for Space Travel," but most experimenters outside of Germany referred to it as the "German Rocket Society"—had begun the series of liquid-fuel experiments which were soon to become the most widely publicized experiments in this field. German experimentation thereafter for several years was to be the product of group effort.

The VfR was founded at Breslau, Germany, on June 5, 1927. It was to be followed by many similar organizations, in the United States, England, India, Holland and elsewhere. To these the VfR was the original stimulus; its experiments for the most part were the starting point from which the others commenced their work.

The *raison d'être* of the societies was primarily mutual encouragement, plus pooled resources and the raising of funds for experiment. An incidental result was the publication of journals and reports which hastened the spread of technical information on liquid-fuel rockets, and thus made it possible for many additional experimenters to contribute, through ideas, discussion and tests.

Early members of the VfR included some of the foremost "names" of European rocketry. Winkler was one of the founders and became the first president. Valier was a founder. After the organization had been announced, Oberth and Hohmann were invited to join, and did. Others who became members were Nikolai Rynin and Esnault-Pelterie. Within a year the society had more than 500 members; by September, 1929, the number had increased to 870. It rose to more than 1,000 soon afterwards; a

measure of the European interest at that time in matters interplanetary.

Few of these members, of course, had any conception of the small and unimpressive start that would have to be made toward the magnificently fantastic promise of the society's name. The books spoke in broad terms of "escape velocities," jet velocities, miles a second, and the like. But as yet there existed in Germany only the tiny *Kegeldüse*, and even this diminutive motor was destined not to be tested until 1930.

Funds that came in from members enabled the society to acquire parts of Oberth's famous, but so far useless, rocket. The most active group, which included Ley, Oberth's former assistant Rudolf Nebel, and a pleasant, quick-minded young German named Klaus Reidel, immediately began to work on other plans, too. Nebel revived an old idea of his: that instead of trying to construct a giant rocket for altitudes beyond the capacity of any experimenter of the day, a small rocket should be built which could at least shoot, thus providing some basic experience.

Nebel's suggestion was adopted, and the group set out at once to construct the first *Minimumrakete*—"Mirak" for short. In designing it, Nebel imitated a skyrocket as closely as possible. The artillery-shell-shaped head was made of cast aluminum, and was to serve as the liquid-oxygen tank. The top, which could be unscrewed, provided the fill-hole, and also contained a spring-controlled pressure valve. The motor, a version of the *Kegeldüse*, was fastened to the copper bottom of the oxygen tank, so that it would be immersed in the liquid. In place of a guidestick, Nebel designed a tubular gasoline tank. The fuel was to be forced into the motor by gas pressure, supplied by a carbon dioxide cartridge like those used in charging soda-water siphons.

The first Mirak was constructed between Christmas of 1929 and June of the following year. In September it was tested on a farm near Bernstadt, in Saxony, Germany. After three or four runs in which it showed promise—but was not released for flight —it exploded.

The Second Mirak was completed two months later. It was similar to the first, except larger. By the time it was ready to test, the society had acquired an official proving ground, an old first World War ammunition dump in Reinickendorf, a suburb of Berlin.

It was there the Second Mirak underwent its test. It performed about like the first, and finally exploded. The experimenters concluded that placing the motor in the oxygen was not practical. Accordingly, plans were made for a Third Mirak which would have several improvements. The motor was to be placed outside the oxygen tank. Two "sticks" were to be used instead of one; the second to contain nitrogen under pressure to feed the gasoline.

To permit the development of a better motor, a proving stand was constructed out of the steel launching rack which had been built by UFA for Oberth's altitude rocket. A rather crude lever scheme was devised to measure thrust, and some controls arranged so that the motor under test could be turned on and off from a safe distance. A series of experiments then began which ended with the production of a standard small motor, referred to by the experimenters as the "egg." It was about the size of a hen's egg, but was cylindrical in shape, with spherical ends; made of spun aluminum, very thin, and fashioned in two parts which were welded together to make the motor. This fragile motor, intended to be water cooled, weighed about 3 ounces without its water jacket, and yielded a thrust of 50 to 70 pounds. The calculated exhaust velocity, at the upper thrust figure, was about 6,500 feet per second.

The VfR experimenters now had a motor for their third Mirak, but the Mirak itself was never assembled. Klaus Reidel had worked out a simpler idea. He fastened two cylindrical tanks to a motor and made a rocket without so much machining and fuss as the Miraks required. In a day or two the first small rocket of this kind was put together, and tested on May 10, 1931. Reidel had not expected it to fly, for the first model was heavy and crude, only designed as a tryout of the scheme. Despite its weight it rose slowly about 60 feet in the air. At that point a fuel tube burst, and the impromptu flight came to an end.[2]

Four days later it had been completely repaired, partly redesigned to reduce the weight, and was ready for another test. This

[2] So far as I know, the data on this and subsequent experiments of the VfR have never been published in technical engineering form. The material given here comes from articles written by Ley a considerable time afterward for *Astronautics*, for various semitechnical and popular magazines and for his recent book *Rockets, the Future of Travel Beyond the Stratosphere* (Viking, 1944).

time, it had a name—it was the "First Repulsor"—and the shot took place on May 14. The Repulsor rose about 200 feet, made a very erratic flight, and crashed to the ground.

Less than two more weeks elapsed before the Second Repulsor was ready. Made of the parts salvaged from the First Repulsor, it was almost identical in construction with its predecessor. Like the first it was unstable in flight, ultimately dashing itself to the ground. This shot took place on May 23, 1931.

By the beginning of June the Third Repulsor had been completed. It was more compact and sturdier than the others; the fuel tanks were closer together and a parachute had been added at the rear. This parachute was to be ejected at the upper part of the trajectory by a small charge of gunpowder, set off by a timer. Unfortunately the parachute release did not work as planned. The rocket flew to an altitude of about 1,500 feet, at which time the parachute was thrown out, though the motor was still operating. The chute was simply torn off, and the projectile continued to rise another 500 or 600 feet. When it fell, it was completely smashed.

In the next few weeks the VfR experimenters made and shot three more Repulsors of the same type as the Third. They performed variously, but none was satisfactory. Pooling ideas, the group then designed a new and very much better rocket, the Fourth Repulsor. This was of the type usually described as a "one-stick" rocket or tandem-tank. The other Repulsors, of course, had been "two-stick" or parallel-tank design.

The Germans reportedly had astonishing success with their final, one-stick type of Repulsor. The first was tested in August, 1931. It rose for more than 3,000 feet, at the top of which the parachute blossomed out as sweetly as could be, and the rocket came gently back to earth.

Subsequently, several more Repulsors were built. One is said to have reached an altitude of better than a mile. Another, accidentally shot at an angle, flew more than three miles.

By the end of 1931 the VfR had made 87 complete rocket shots with liquid-fuel rockets, and had carried out 270 proving stand runs of rocket motors, not counting the Miraks. In addition to the standard Repulsor motor some work had also been done toward developing a larger motor, to provide a thrust of around 140 pounds. The first such motor, however, was a disappoint-

Mr. Lyon again appeared in the newspapers in July, 1931, when it was stated that a change in plans had occurred: the shot would now be made in the African desert, about 100 miles south of Tripoli. The first rocket was to reach an altitude of 36,000 feet and would carry instruments. It would also carry "two birds and two mice, for the purpose of studying their reactions under the influence of cosmic rays."

In September, the New York *Times* carried a further article about Mr. Lyon. This time it was reported that he had already shot a rocket carrying "a canary bird and a mouse" to a height of one mile, from which they had descended by parachute, no worse for the experience. The *Times* reported that a new and larger rocket was then being constructed in Paris for Mr. Lyon, and that the shot would be made in the Libyan desert in January or February, 1932.

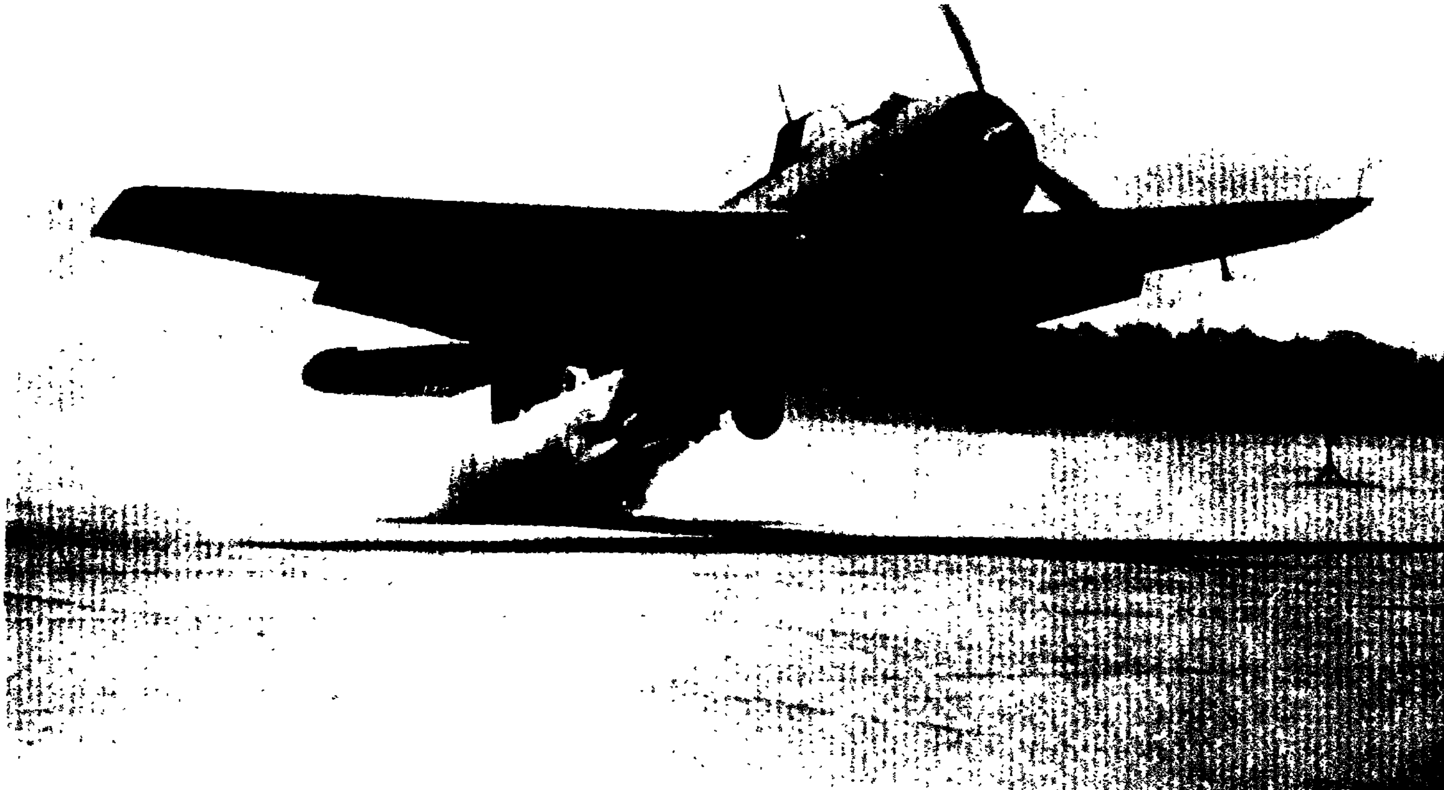
No further word from the Lyon experiments was ever heard. There were nevertheless plenty of competitors for attention. On June 4, 1931, a young stunt flyer at Atlantic City, William G. Swan, attached ten dry-fuel rockets to a 200-pound glider, and thus apparently became the first American to fly a rocket-powered craft. The glider was launched into the air with an elastic cord; then the pilot closed a switch to ignite the rockets. Only one of the ten rockets fired; it drove the plane about 1,000 feet. The next day the experiment was tried again, this time with twelve rockets. They all worked, and the craft remained in the air eight minutes.

Applying an idea of Max Valier's, that of attaching rockets to a sled, a young experimenter at Syracuse, New York, went spinning across the ice of Lake Oneida, in upper New York State, in March, 1931. He was Harry W. Bull, who was later to make some important contributions to liquid-fuel rocket research. His rocket-sled took off well, but the first battery of rockets swerved it from the path which had been cleared across the mushy surface of the ice, and the experiment ended a short distance from where it started, in a cloud of smoke and fire.

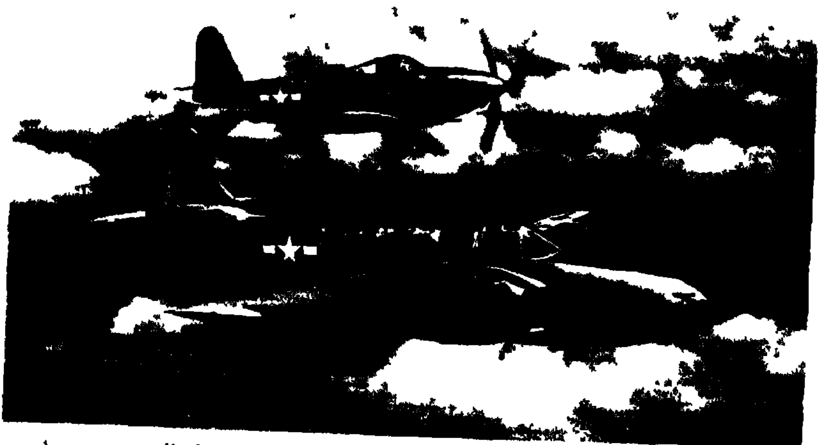
2.

The most successful proponent of dry-fuel rockets in this period was a German, Reinhold Tiling, who on April 15, 1931,

Rocket launching ships in action, a salvo of rockets heads for the beach in preparation for an amphibious landing in the Pacific (*U S Navy photo*)

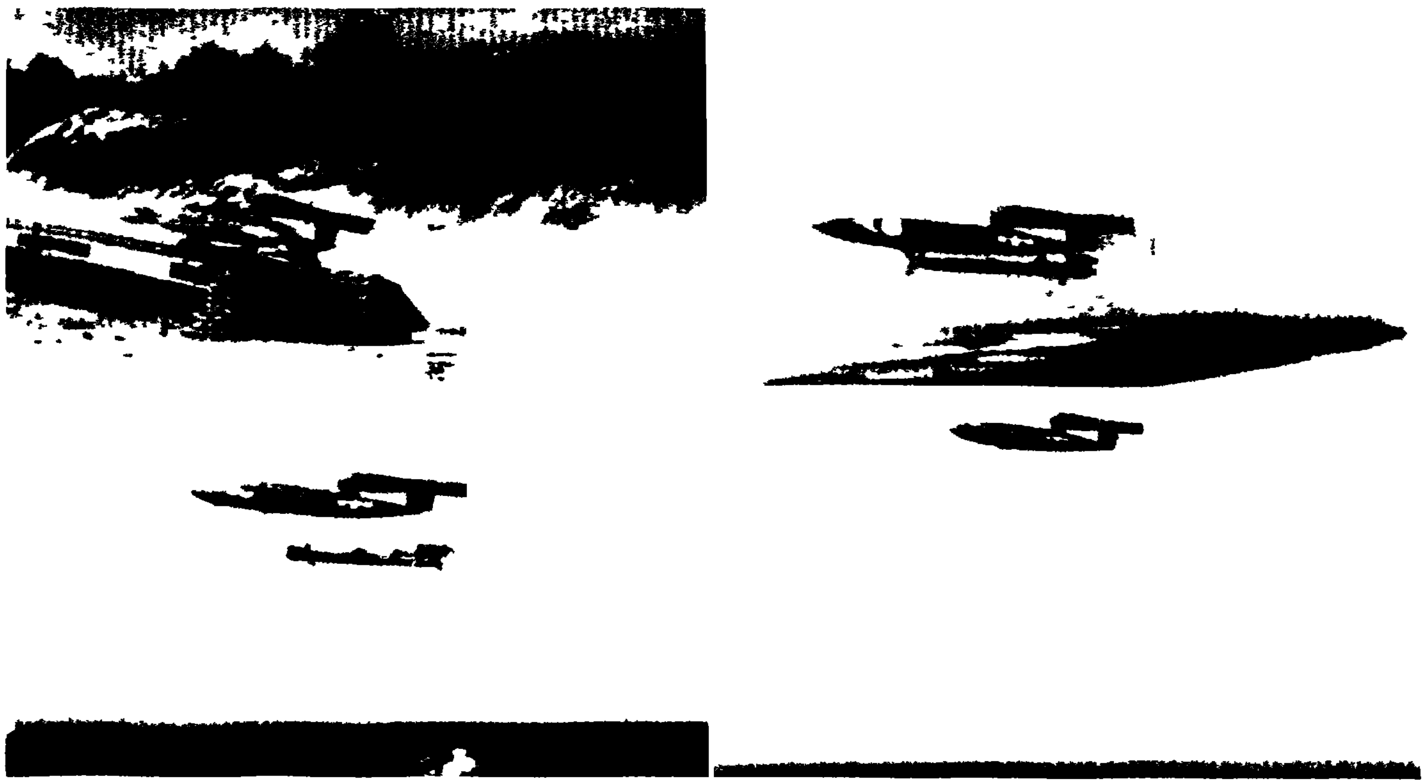


A Navy Avenger takes to the air with the powerful assistance of four jato units attached to the fuselage. Such jatos reduce the takeoff run as much as 60 per cent. (*U. S. Navy photo*)

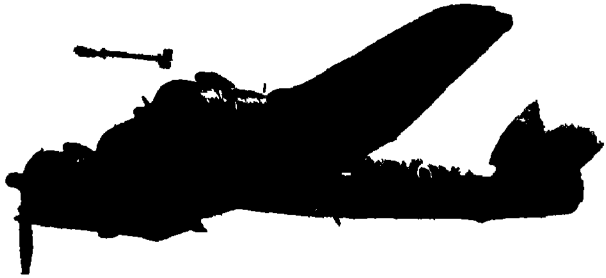


A jet-propelled P-59A Airacomet in flight with a conventional P-63 Kingcobra. The P-59A was the first jet-propelled plane produced in the United States. *(Bell Aircraft Corp. photo)*

Close-up view of a Bell jet-propelled plane, showing air intake of one of the engines. *(Bell Aircraft Corp. photo)*

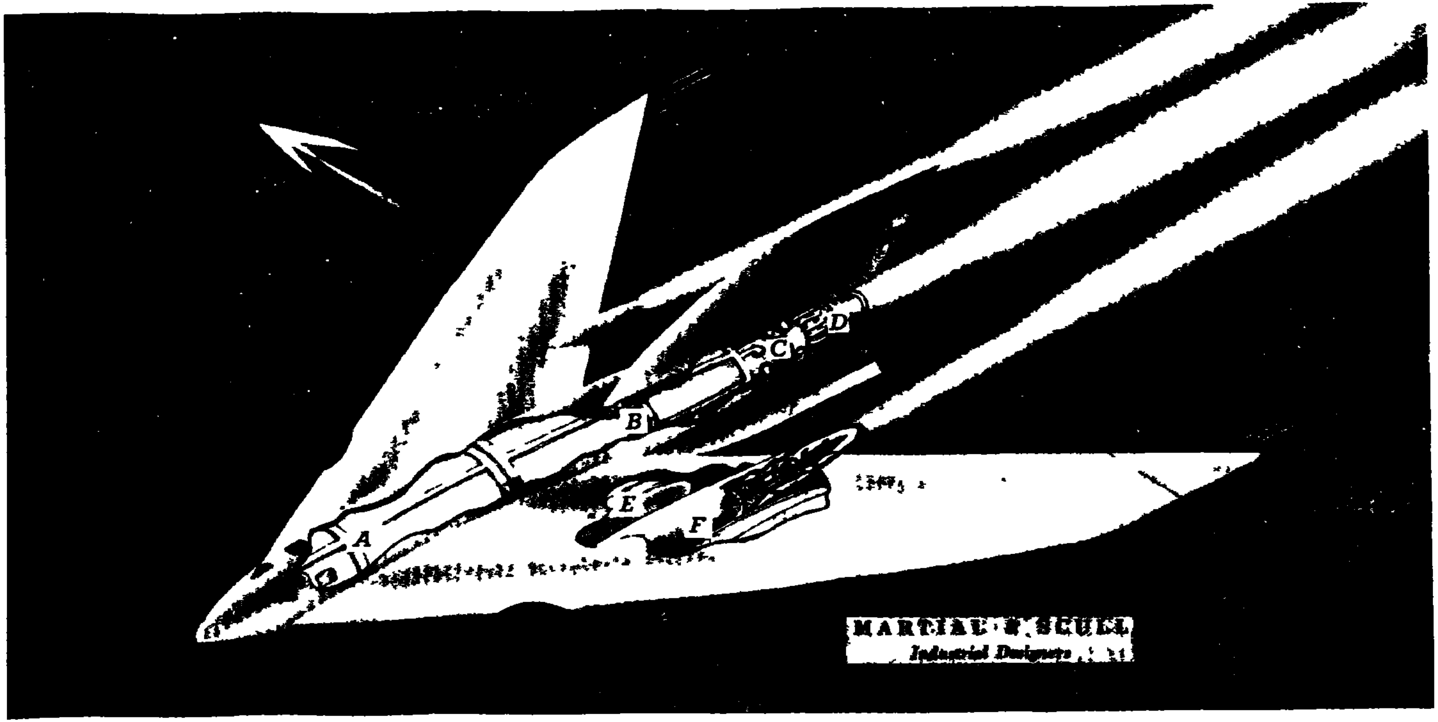


The new U S buzz bomb adapted from the German V-1 robot bomb *Top left* beginning of the takeoff run, *top right* the bomb leaves its launching track propelled by the launching rocket and its own engine, *lower pictures* the launching rocket falls away and the buzz bomb proceeds under its own power (*U S A F Paramount Newsreel photo from Acme*)



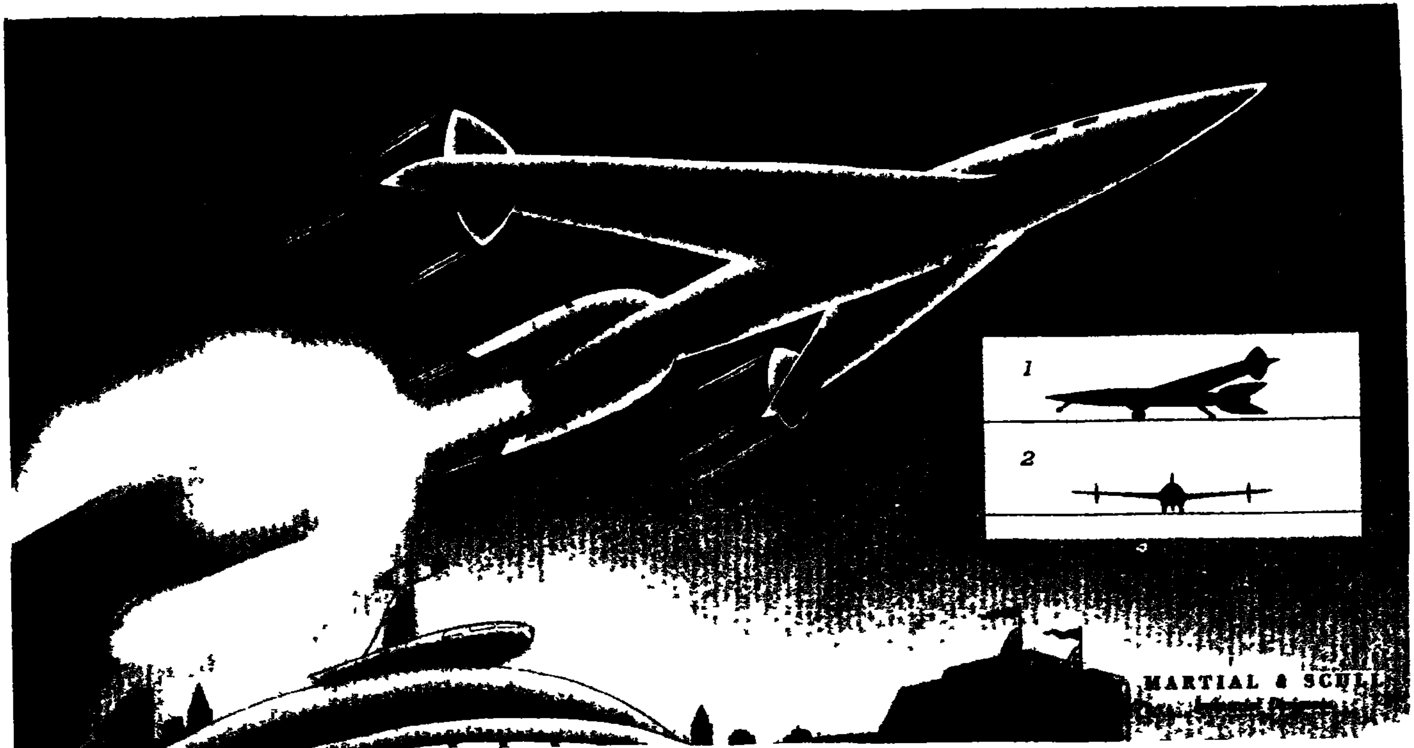
A British Beaufighter launching two of its rockets at a distant target. *(British Information Services photo)*

An R.A.F. ground crew loading rockets in the underwing launchers of a Typhoon. *(British Information Services photo)*

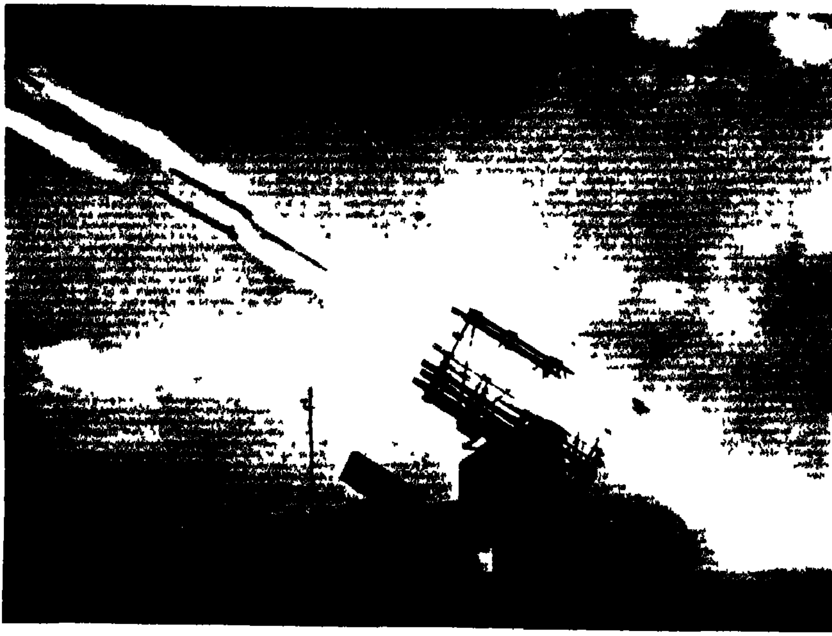


A combination turbo-jet and rocket motor aircraft, visualized by Jacques Martial and Robert C Scull, Industrial Designers Such a craft could possibly fly at velocities of 1500 miles an hour in the stratosphere

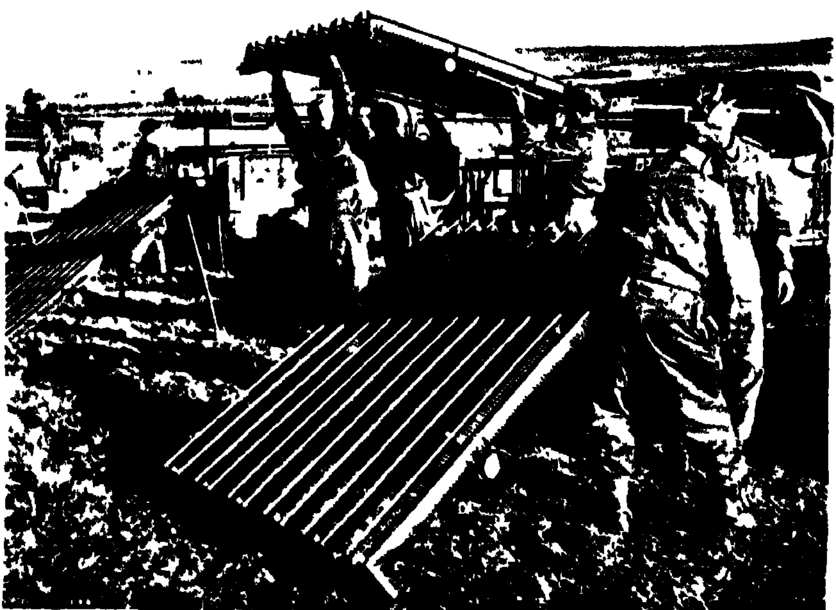
A. Pressure passenger cabin, B Fuel tanks, C Pumps, D Rocket motor, E Fuel tanks feeding turbo-jet engine, F. Turbo jet engine.



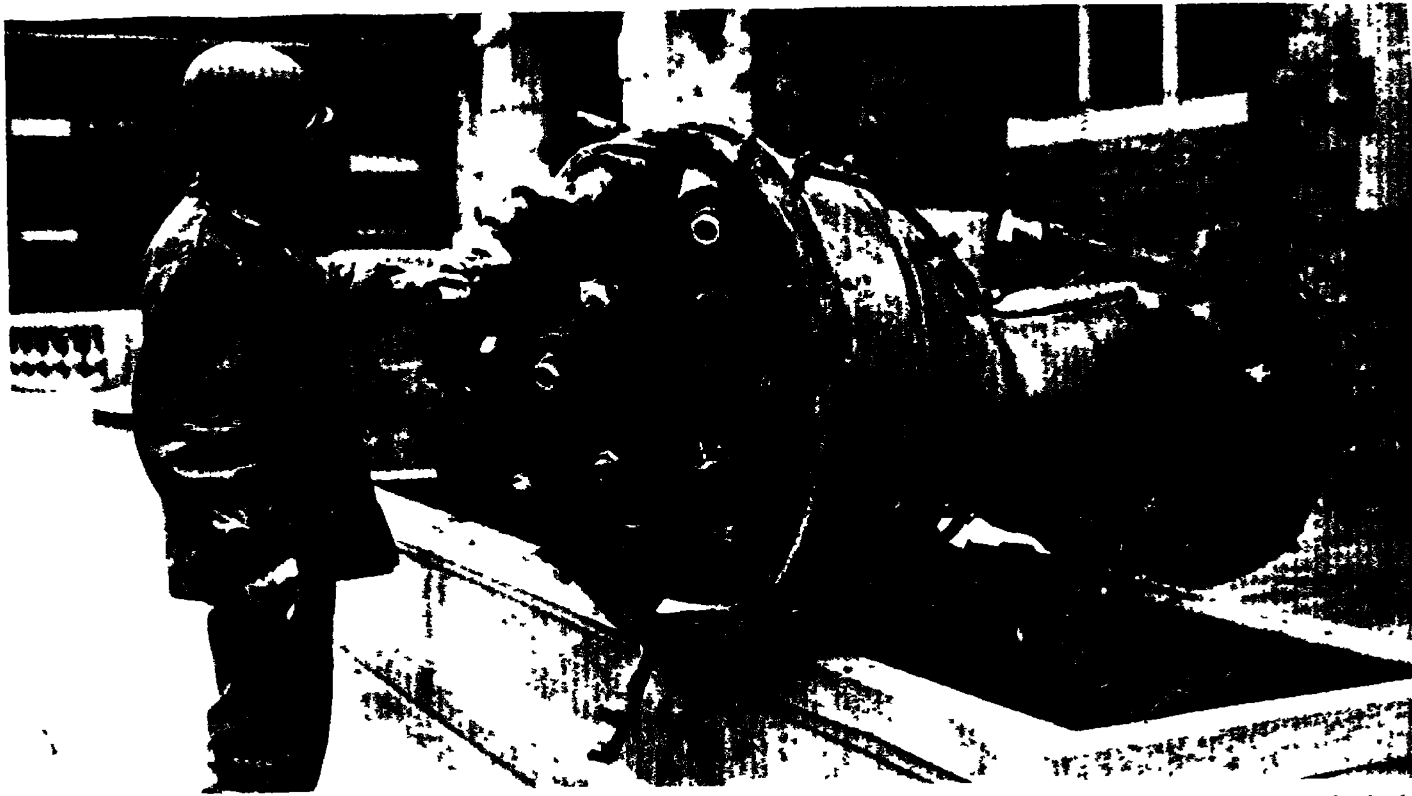
Aircraft driven by a true rocket motor for long distance trajectory flight partly through the upper stratosphere. Visualized by Jacques Martial and Robert C Scull, Industrial Designers.
1. Side view silhouette of aircraft, 2. Front view silhouette of aircraft.



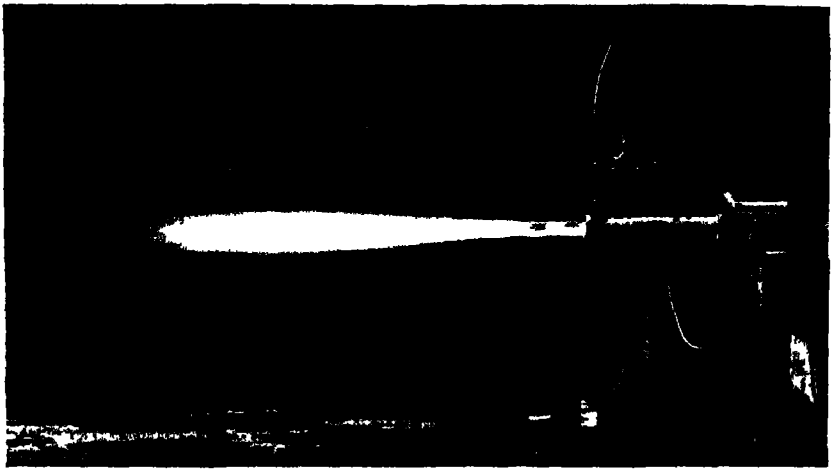
British antiaircraft rocket guns in action (*British Information Services photo*)



Antiaircraft rocket launchers can be light in construction, and require no recoil mechanism, as these British launchers show (*British Information Services photo*)

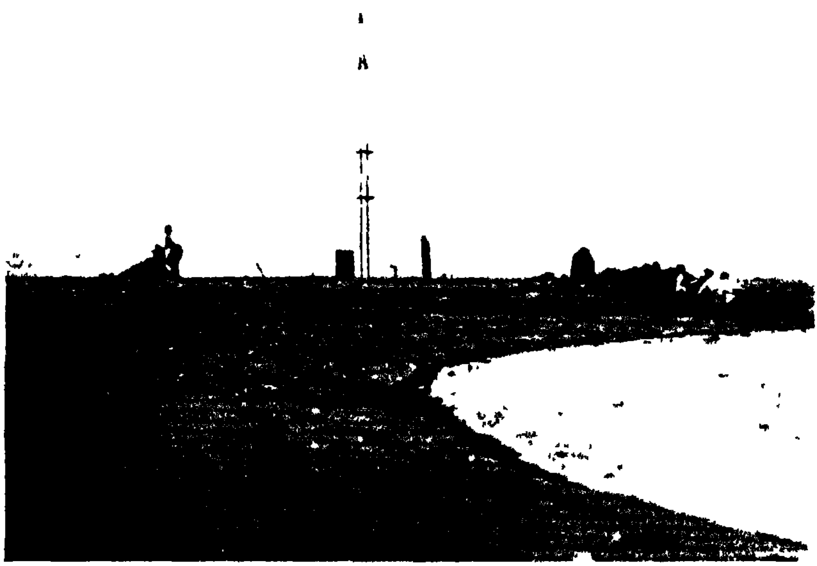


The motor of a German 'V-2' rocket. Apparatus at the rear are fuel-injection ports, where liquid oxygen and alcohol are mixed and forced into the combustion chamber. (*U. S. Signal Corps photo*)

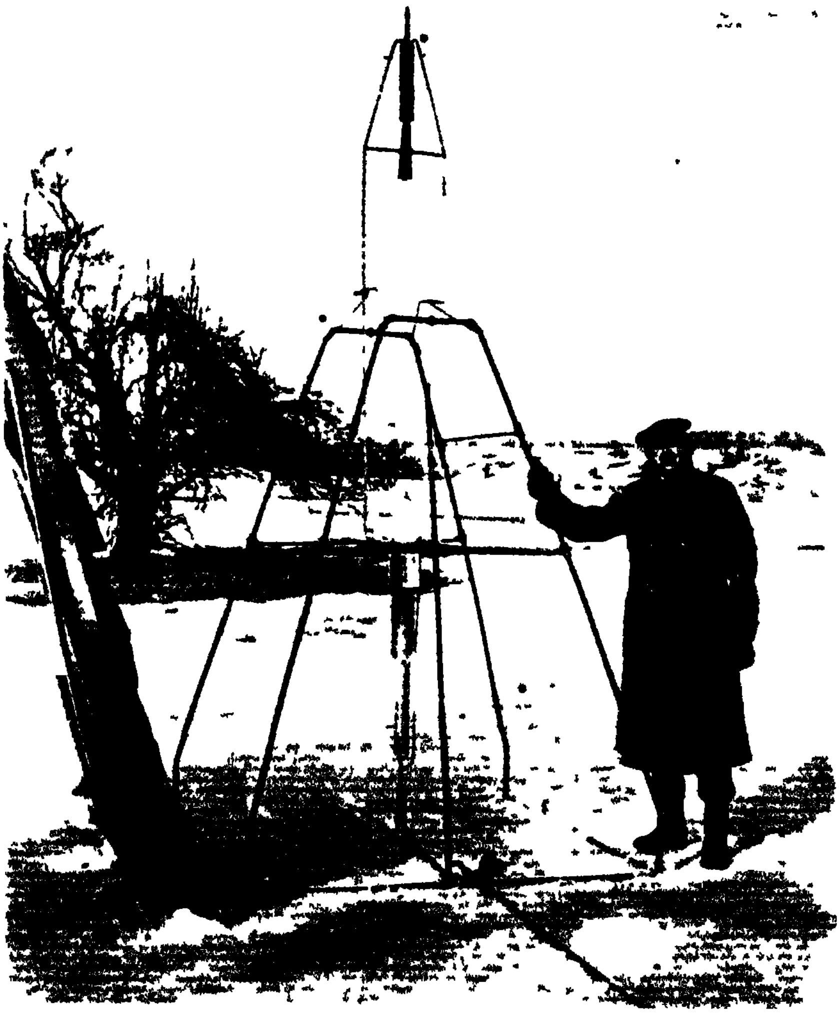


A liquid-fuel motor in operation. Note "standing waves" in the jet. The thrust of this small motor is 350 pounds. (*Reaction Motors photo*)

A 3,000-pound liquid-fuel motor ready for testing at the proving grounds of Reaction Motors, Inc. Examining the motor are Rear Admiral H. L. Brinser, USN, James Wyld and Lovell Lawrence, President of RMI. (*Reaction Motors photo*)



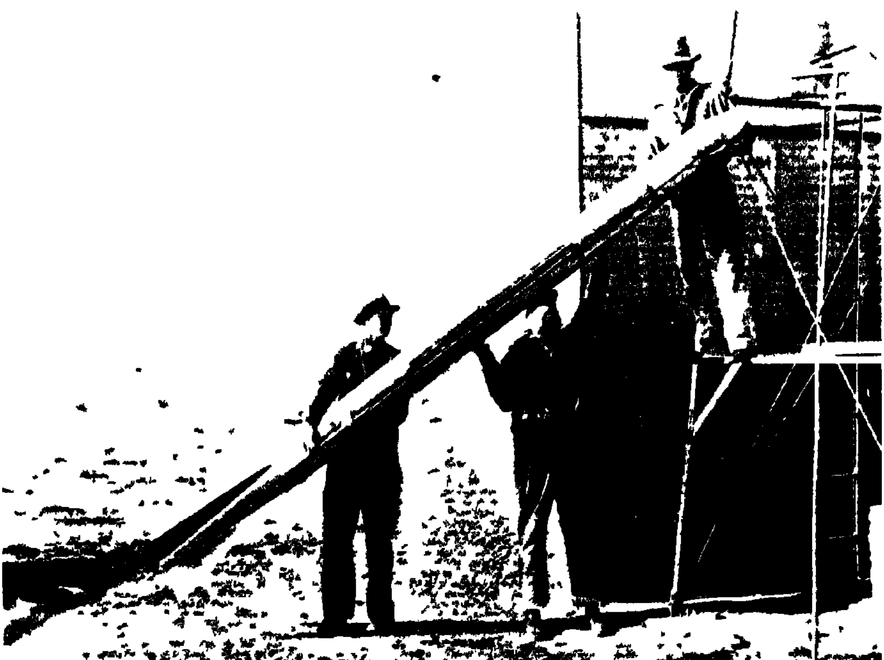
Flight of the American Rocket Society's No. 2 liquid-fuel rocket, May 14, 1933. This is the first photo ever taken of a liquid-fuel rocket in flight. (*Acme photo*)



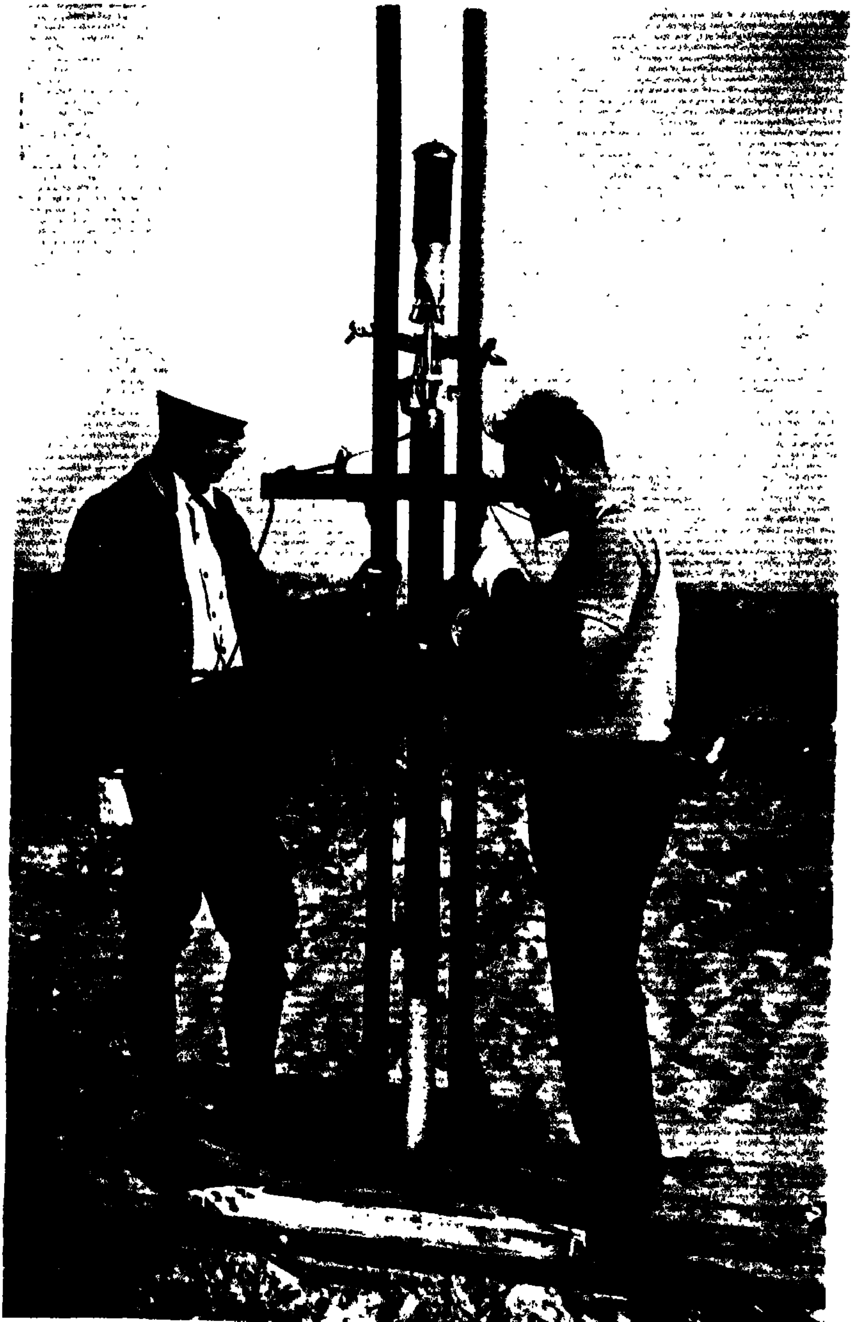
The world's first liquid fuel rocket and its designer, Dr Robert H Goddard This historic picture was taken just before the shot at Worcester Massachusetts in 1926

One of Dr Goddard's large gyrostabilized rockets in flight (1935)

Dr Goddard at work in his laboratory



A large Goddard rocket being loaded into the launching tower in New Mexico



One of the first liquid-fuel rockets to reach the speed of sound, being fueled before a test on Staten Island, New York, in 1934. The designer, John Shesta, is at the left; the author is shown at the right, pouring fuel into the rocket's tank. (*American Rocket Society photo*)

demonstrated a new type of powder rocket on a lake near Osnabrück, Germany. He had the backing of wealthy Count von Ledebour, of Osnabrück, and possibly also of the German government. He evidently had been secretly experimenting for some time before his public demonstrations. His rockets were sleek, finished and complete, like factory products.

The typical Tiling rocket consisted of a streamlined body about four feet long, to the lower end of which were fastened four large, equally spaced fins. Into the hollow body could be inserted a prepared cartridge of propellant, formed on a hydraulic press after a method which Tiling patented. The solidly pressed powder charge contained a central channel or core about one inch in diameter, filled with powder somewhat more loosely pressed, in such a way that the tightness of the pack increased from front to back. In action, the looser powder of the central core burned quickly, providing quick thrust for the takeoff and leaving a relatively large inner surface in the hard-packed charge, which could therefore burn more rapidly than a solid rocket of the "brander" type.

Tiling made the powder cartridges himself. Since they could readily be inserted into the bodies of his rockets, the rockets could be shot repeatedly. He sometimes referred to these projectiles as "rocket airplanes" or "rocket ships," because at the upper part of their flight, two of the fixed vanes suddenly jackknifed forward, providing wing surfaces which brought the rockets down in a long glide.

Tiling patented another landing idea, but apparently did not build any rockets to the design. This was a scheme for having all of the fins fold forward on hinge joints to form a windmill-like fan which was expected to bring the rocket down with a motion similar to that of an autogyro rotor.

Tiling made a great number of successful shots, demonstrating his rockets not only in Osnabrück, but in several other German cities. On one occasion at the Tempelhof Airdrome in Berlin one of his rockets was caught by a gust of wind and deposited among the spectators. Nobody was hurt but the Berlin police forbade any further shots.

Tiling's rockets reached altitudes from 2,500 to about 5,000 feet. He produced several different types, mostly just variations in the shape of the bodies; the motive power remained the same.

He told reporters he believed he could readily shoot 60,000 feet. On November 30, 1931 at Wandergoog in the East Frisian Islands, he shot a "space ship" which newspaper reports declared had reached an altitude of six miles. This would certainly have been a record, but it was not substantiated by any evidence, and is generally disbelieved.

Tiling's announced ambition was to establish rocket-mail lines over Germany and ultimately across the Atlantic, though he admitted that liquid fuels would be required for the latter shots. Reporters said he was already at work on liquid-fuel experiments, but if this were true, he did not make the change quickly enough. On October 10, 1933, while pressing some extra-large rocket cartridges according to his own method, his machine exploded, killing him instantly and fatally injuring his two assistants, one of them Angelika Buddenbohmer, whom Tiling often referred to as the "first woman rocket experimenter."[1]

3.

On the evening of March 21, 1930, about a dozen men gathered in an apartment at 450 West 22nd Street, in New York City, to form an ambitious society for the "promotion of interest in and experimentation toward interplanetary expeditions and travel . . . the stimulation by expenditure of funds and otherwise of American scientists toward a solution of the problems which at present bar the way toward travel among the planets, and the raising of funds for research and experimentation."

It was the first meeting of a group which then called itself "The American Interplanetary Society" and was subsequently to become the American Rocket Society.

The leader of the original group was David Lasser, a graduate of the Massachusetts Institute of Technology, then editor of a popular fiction magazine called *Wonder Stories*. Mr. Lasser became the first president of the society. Others included C. P.

[1] There were, of course, several women interested in rocket experimentation. Miss Lee Gregory, a member of the American Rocket Society, became interested in rocketry early in 1930, and took part in virtually all of the society's rocket shots. Mrs. Robert H. Goddard may also be listed as a rocket enthusiast. She has aided Dr. Goddard in most of his experiments and virtually all of the photographs of his shots and apparatus have been made by her.

Mason, a writer and editor, who was the first secretary; Fletcher Pratt, the writer; Clyde J. Fitch, an engineer; C. W. Van Devander, a newspaperman; Lawrence Manning, a writer and businessman: Nathan Schachner, writer and lawyer; Dr. William Lemkin, a chemist. Mr. Van Devander, who is now a newspaperman in Washington, D. C., became the editor of the society's first publication, known as the *Bulletin.* I was elected vice-president, and given the assignment of organizing a research program.

The society's first public activity was to arrange a ceremony in which Captain Sir Hubert Wilkins, the explorer, presented to its library an old copy of one of the earliest books on interplanetary travel, *The Discovery of a New World*, by John Wilkins, Bishop of Chester, written in 1640. Bishop Wilkins was a distant ancestor of Sir Hubert's. In the same ceremony, the explorer became a member of the society.

The second public appearance of the organization was more spectacular. Lasser had learned somehow that Esnault-Pelterie, who had gained great attention abroad for his *L'Astronautique* and his addresses on rockets and interplanetary flight, would presently visit this country. Lasser cabled him, asking him to address a public meeting under our auspices. Somewhat to the society's astonishment, he accepted.

Lasser made arrangements to use the auditorium of the American Museum of Natural History for the meeting. This auditorium holds about 1,500; a very large crowd for an unknown organization to draw. So as an added attraction it was arranged with UFA's New York office to show a part of *Frau im Mond*, which had been retitled in English and brought out in this country as "A Girl in the Moon." Impatient with the romantic parts of the story, which were very badly done in any case, the society's executive group cut the film until only the technical portions, showing the fictional space flight, remained.

This double attraction then was widely placarded throughout the city. Admission was to be free. Long before the time of the meeting there was clear evidence that the auditorium would be amply filled. The museum authorities insisted that the crowd would be so great extra guards would be necessary. Everything was set for a big meeting—and then Esnault-Pelterie, who had arrived on schedule and had worked with the society's members

on the preparation of his speech, sent a devastating note. He had a cold, and could not make the address. When this note arrived, the meeting was only three or four hours away.

Hastily it was decided that a member of the society should give Esnault-Pelterie's talk in his place. Lasser, as chairman of the meeting, announced the substitution in an unmistakable way, but there were nevertheless many present who thought the stand-in was Esnault-Pelterie himself, and came clamoring to the platform for autographs. The crowd was so large less than half was able to find a place in the auditorium, and the entire meeting had to be gone through twice, to take care of the persistent overflow. More than 1,000 people waited outside throughout the first performance, and nearly filled the auditorium again at ten o'clock.

The society was thus well launched. The membership climbed. Among the well-known American scientists and engineers who joined were Dr. H. H. Sheldon, professor of physics at New York University; Dr. Alexander Klemin, head of the Guggenheim School for Aeronautics at New York University; John O. Chesley, of the Aluminum Company of America; Dr. George V. Slottman of the Air Reduction Company, and Dr. James H. Kimball, of the United States Weather Bureau, and Dr. Goddard. Within three months of its foundation, the society was able to begin publication (at first in mimeograph form) of the *Bulletin*, later called *Astronautics*, which has since become the most complete single source of news, discussion, engineering information and experimental data in the field of rocketry. The publication is now called *The Journal* of the American Rocket Society, and appears quarterly.

Early in 1931 it became possible for Mrs. Pendray and me to go abroad. We planned the trip in such a way as to enable us to see what the European experimenters were doing. The society named us its official representatives.

Our journey at length brought us to Berlin, after some unsuccessful attempts to get in contact with Darwin O. Lyon in Italy and Esnault-Pelterie in France. Both of these men were away at the time of our arrival, but in Berlin we found Ley very much at home and eager to show us the work of the VfR at the *Raketenflugplatz*—the VfR's "rocket flying field."

The *Raketenflugplatz*, about which we had already heard a

great deal, turned out to be a large muddy area covered by the remains of wartime buildings and entrenchments for the storage of explosives. It abounded in earthen embankments, which made good shelter for the spectators, but prevented the control operator from seeing what was going on at the proving stand.

We stood on one of the embankments about a hundred feet away from the proving stand. After considerable shouting of orders, the fuse which was to ignite the motor began to burn. In a moment the gasoline was turned on. Then came the oxygen. The flame suddenly became brilliantly white, narrowed down to a sword's length of roaring power. The sound was so intense it hurt our ears; it seemed impossible that the small motor could stand so much heat and pressure. But it did; the test continued for about sixty seconds, the motor being cooled by a stream of cold water running through a pipe into its cooling jacket.

The official representatives of the American Society, who had never before seen a liquid-fuel test, were very much impressed. The power of liquid oxygen and gasoline as propellants was self-evident. We felt certain that the American Society should begin its own liquid-fuel experiments at once.

With Ley's help I made some notes about the motor tests and the German Mirak experiments for a report to the society. Ley not only helped us get into our notes the technical details of the German motors, but made an agreement to exchange technical information by mail; a sort of international understanding based on the sound idea that rocketry would advance faster with free exchange of ideas among experimenters.

Our report on the German experiments was given before a large meeting of the society on the evening of May 1, 1931, and appeared in a somewhat condensed version in the May issue of the *Bulletin*. It marked the beginning of liquid-fuel experimentation in this country, other than the work Goddard was carrying on then in New Mexico. Shortly after the May meeting, H. F. Pierce, who was later to become president of the society, proposed that work begin at once. An experimental committee was formed. Mr. Pierce and I designed, more or less by rule of thumb and what guidance we had from the German data, our first liquid-fuel motor and rocket.

In general shape it was not unlike the German "two-stick" Repulsor. The two cylindrical tanks were each five and a half

feet long. They were gripped at the top by a frame which also supported the turn-on valves, the motor, the cooling jacket and a cone-shaped nosepiece which contained a parachute. At the rear were large sheet-aluminum vanes. The fuels were gasoline and liquid oxygen, forced into the motor by gas pressure, as in the Repulsor. The parachute mechanism was kept closed by gas pressure in the gasoline tank, and sprang open when the pressure went off, thus being set to eject the chute at the end of the firing time of the motor.

The motor itself was similar to the German in outward appearance, being 3 inches in diameter and 6 inches long. But we had been unable to obtain a spun-aluminum motor like that of the Germans, and used cast aluminum instead. The rocket, loaded with fuel, weighed 15 pounds, and the motor was calculated to have a thrust of 60 pounds, providing an expected acceleration of 3g.

This first rocket, crudely constructed and not really expected to do much more than serve as a stand to test the motor, was completed in time to show to the members of the society in February, 1932. Preliminary tests then disclosed many weaknesses. Parts were later changed and improved. The rocket was finally given its first burning test on November 12, on a farm near Stockton, New Jersey. Members of the society had hauled lumber there and built a small wooden launching rack, equipped with a spring-operated thrust-measuring device. The motor burned between 20 and 30 seconds, providing a thrust of 60 pounds.

4.

Much encouraged by the performance of the motor, the committee proceeded with the construction of a new rocket—or in reality, the reconstruction and simplification of the old one.

This task was put in the hands of Bernard Smith, a young member who had considerable mechanical talent. He removed the awkward superstructure containing the parachute, brought the fuel tanks close together and clamped the motor directly between them, simplified the valves, substituted light balsa-wood vanes for the large metal fins of the earlier model, left off the cooling jacket, and rounded the forward end of the rocket with a streamlined bonnet. The bonnet had an opening at the front

to admit air, which he believed would do the cooling job nearly as well as water.

Known as ARS Rocket No. 2, it was shot from a temporary proving field at Marine Park, Great Kills, Staten Island, New York, on May 14, 1933. It reached an altitude of 250 feet, after firing about two seconds, and was still going strong when the oxygen tank exploded. It had been calculated that the rocket would reach an altitude of about a mile, but of course the bursting of the oxygen tank immediately released the pressure, the motor ceased functioning, and the rocket dropped into the water of lower New York Bay.

The cause of the accident could not definitely be determined, but the evidence indicated that lack of check valves in the feed line had permitted some mixing of the fuel and oxygen in the oxygen tank. This probably occurred during a preliminary standing test a few minutes before the shot, when the motor and fuel-feed system had worked excellently.

In spite of the accident the members of the society considered this a successful shot—successful at least in the sense that a liquid-fuel rocket had actually been seen to leave the ground under its own power. Three new rockets were almost immediately projected, representing the ideas of several different groups.

These designs were approved by the experimental committee, and presented in *Astronautics* for October, 1933. Work commenced at once. Rocket No. 4, designed and constructed by John Shesta and a small committee he had chosen to help him, was the first completed. Its motor had four nozzles; its tanks were streamlined and arranged in tandem. It was an extremely sturdy and well-built rocket, and the multiple nozzles projecting from a single combustion chamber permitted forward thrust without the inherent weakness of structure and fragility of the Repulsor design. (For the motor of this rocket, see FIG. 5.)

The motor, however, had not been proving-stand tested, and the experimenters had no means of knowing how it would stand up, or what its behavior might be in flight. It was cooled simply by a water jacket, and its thin metal nozzles were made of brass. The thrust was calculated to give the rocket an initial acceleration of 3*g*, increasing to about 5*g* as the fuel was used up. The estimated burning time was about 30 seconds.

The first attempt to shoot the rocket disclosed that the fuel

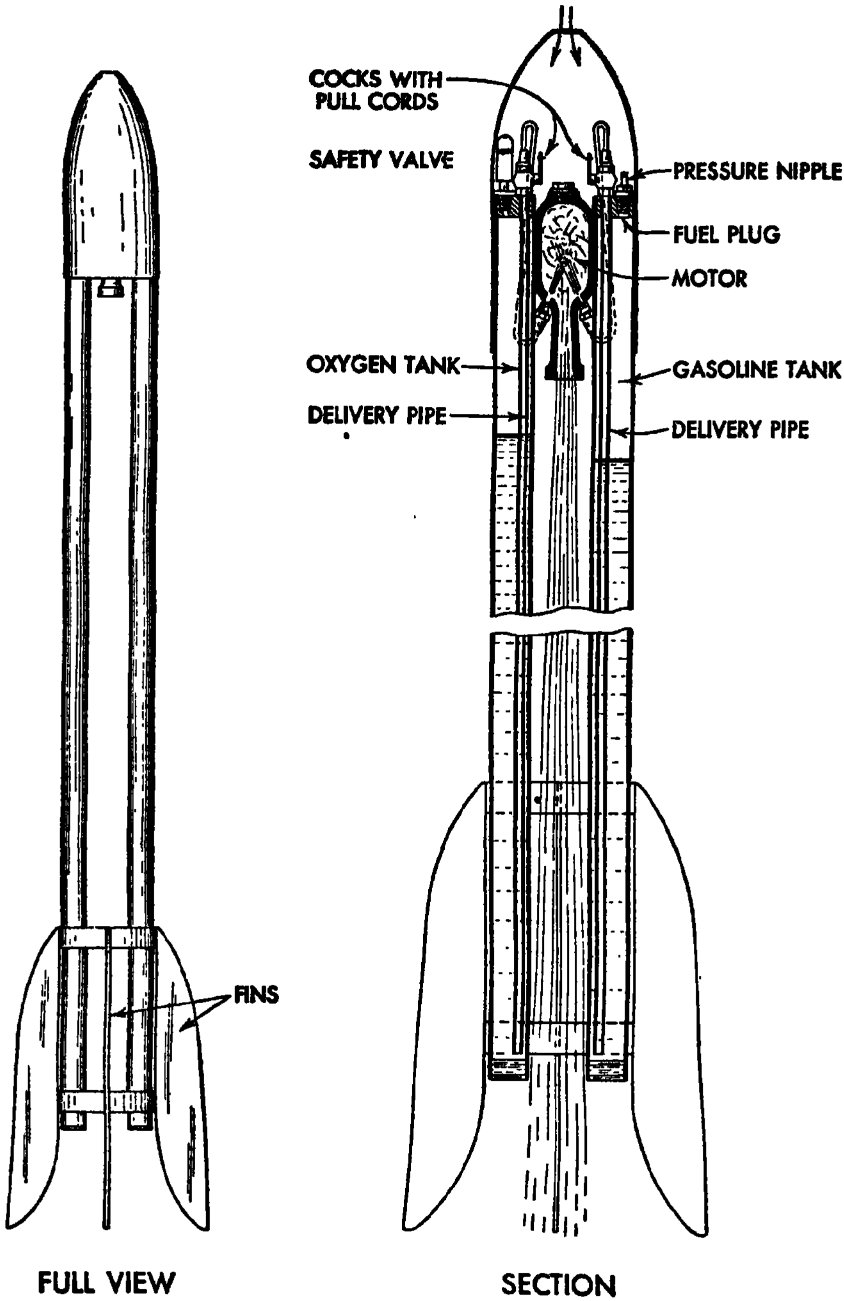


Fig. 16. Design of the ARS Rocket No. 2.

inlet ports had not been made large enough, and the rocket failed to rise. On the second attempt, on September 9, 1934, after the rocket had been repaired and the fault remedied, the rocket leaped from the rack in rapidly accelerated upward flight. Its speed and trajectory were carefully observed from three triangulation stations, manned by members of the society who had been trained for the task by Alfred Africano, chairman of the organization's technical committee. In addition, it was photographed by motion-picture and still photographers.

For the first few seconds it performed perfectly, then one of the nozzles burned out, followed quickly by another. This caused the rocket to yaw outward over the bay (this test, like that of Rocket No. 2, was made at Marine Park, Staten Island). Still accelerating, it went a long trajectory, and the calculations of the official observers later indicated that its velocity at one point exceeded 1,000 feet a second—about 700 miles an hour,[2] or nearly the speed of sound.

After about twelve seconds of firing, it became apparent that the air resistance on the rocket was terrific. Still under full fire, the rocket began to weave and "hunt," as though the head resistance were too great for its blunt nose to penetrate. It then took a sharp downward course. Still firing, it struck the water with an enormous splash. The parachute in its forward container had no opportunity to operate, and the rocket was so badly smashed by impact it could not be salvaged, though the tanks were later used in constructing the society's first motor proving stand.

Rocket No. 3 designed by Bernard Smith and myself, was completed next. It was a compact design, with concentric tanks and other theoretical advantages, but was extremely troublesome to construct because of the difficulty of welding the numerous seams, some of them internal. When it was finished, we learned the discouraging fact that it was next to impossible to fuel it normally, because the oxygen, exposed to so much warm metal in the outer large tank, simply evaporated as fast as it could be poured in.

This rocket could undoubtedly have been loaded and shot, perhaps by precooling the tanks with dry ice. But it had already

[2] It thus anticipated Dr. Goddard's 700-mile-an-hour rocket by a few weeks, and may have been the first rocket to reach this velocity.

become apparent, by the time it was ready for testing, that the motor of Rocket No. 3, based on the motor design of Rocket No. 1, would be inadequate. This was demonstrated when Mr. Shesta, following the shot of Rocket No. 4, constructed the society's first proving stand and began putting motors to the test, in April, 1935.

5.

Now it would perhaps seem, with the work Goddard and the German experimenters had already done on the motor, that all its problems should have been solved by the spring of 1935, when the American Rocket Society motor tests commenced.

Possibly Goddard had solved them; the complete data on his motors are not yet available to other experimenters. The Germans had produced a satisfactory motor for limited use, but it was too small for large weight-carrying rockets, it was water-cooled, and it had many deficiencies.

Water cooling, as the society quickly learned, has only very limited value. When motors grow larger and power increases, water cooling becomes relatively less effective. Moreover, the water and its jacket add pounds of extra weight. A motor was needed which would operate indefinitely and not burn out, which would have good efficiency and light weight, and be simple to construct.

The society's first motor proving stand was completed, tested and ready for use by April 21, 1935, when the first series of runs were undertaken at Crestwood, New York. Five motor shapes were shot on that occasion, all being similar in general pattern to those already used or planned for the society's rockets. None stood up under the test.

Three months later, a new series of motors was ready. To simplify the problem of changing styles, shapes and nozzle materials, a sectional motor had been constructed, the nozzle and body of which could be exchanged readily after each run without occasioning the expense and time of making a completely new motor. In the second series of tests, six runs were made, of nozzles constructed from various heat-resistant materials. A Nichrome nozzle stood up well, but not perfectly. All the others burned out.

A third series of tests was shot on August 25, 1935. There

were five runs, this time testing various fuels as well as nozzles and cooling systems. The tests proved conclusively that water would not work as a coolant in a large motor, for a run of more than a few seconds. They showed that even Nichrome would not stand up under a long run. They indicated that for relatively small motors, alcohol was a smoother, better fuel than gasoline: by diluting it somewhat with water, the motors could be made to remain cooler.

A fourth series of tests was made on October 20. By this time a great deal of information had been obtained and was beginning to result in new and better designs.

The tests had shown that the first proving stand, while practical enough for short runs and motors of less than 100 pound thrust, was not large enough for the experiments now indicated. Mr. Shesta was asked to design and build a new and better stand, aided by Messrs. Wyld, Africano, Peter van Dresser and others. On this project they immediately commenced work.

During the period required for the completion of the new proving stand, the experimental committee turned to the problem of aerodynamic design, and began a series of experiments with dry-fuel rockets of many sizes and shapes, to determine whether any broad principles of stability could be discovered. These rockets included both tail drive and head drive, with large fins and small ones; long rockets and short ones; and many varieties of shapes and sizes in between. The tests went on at intervals over about three years, beginning in the summer of 1935 and continuing until September, 1939, though during the latter part of the period liquid-fuel motor tests had also been resumed. The dry-fuel tests enabled the society also to study catapults and other launching schemes, parachutes and parachute releases.

The long and tedious series of liquid-fuel motor tests now began again, but this time commenced to repay the effort. The experimenters had begun to perceive that the only practical solution of the rocket motor problem was to make the incoming fuel do the cooling. This would have the advantage of adding no coolant weight to the rocket, and the heat absorbed from the nozzle by the incoming fuel could be carried directly back into the blast chamber, increasing the efficiency.

Suggestions of this kind had been made by many experimenters, of course. Goddard had patented a motor with a

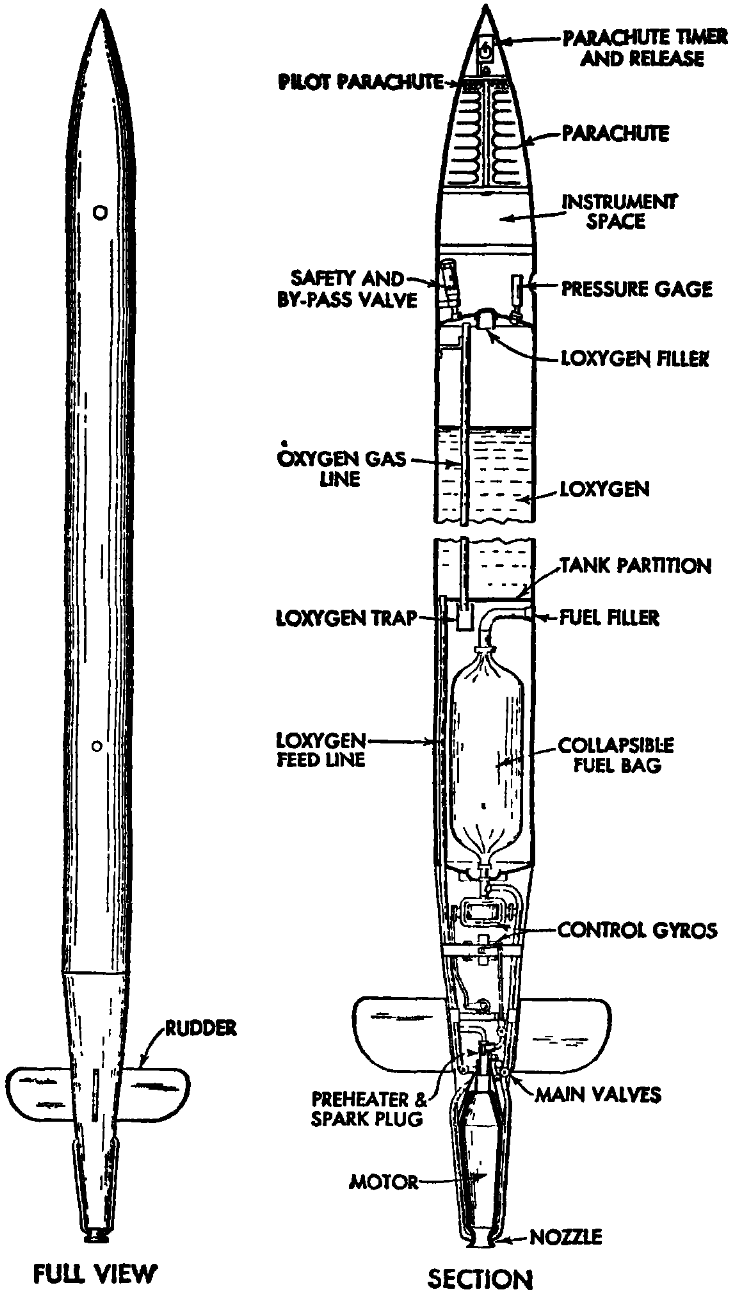


FIG. 17. One version of Mr. Wyld's proposed sounding rocket, with gyro-control, regenerative motor and collapsible fuel bag.

fuel-cooling jacket built into it. Harry W. Bull, following an interesting series of motor tests carried on at Syracuse University, had suggested a fuel-cooled nozzle in a report to *Astronautics* in July, 1932. The German engineer, Eugen Sanger, in a series of experiments at the University of Vienna in 1931 and 1932, had used incoming fuel to cool the throat and combustion chamber of his test motors.

But with the probable exception of Goddard, the first experimenter to produce a simple, practical rocket motor intended for flight and cooled by incoming fuel was James Wyld. His motor was designed as a result of experiences with the society's proving-stand-motors, and was expected to supply motive power for a sounding rocket. It was first described, with a cross-section drawing, in *Astronautics* for April, 1938.

Despite its double-wall construction, the completed motor weighed only two pounds. It received its first test on the society's new proving stand on December 10, 1938. It delivered a thrust of somewhat more than 90 pounds and produced a maximum jet velocity of about 6,000 feet per second, corresponding to a thermal efficiency of about 40 per cent. (See FIG. 7.)

In the same series of runs, a regenerative motor of different design, but working on the same general principle, was submitted for test by Midshipman Robert C. Truax, of the U. S. Naval Engineering Experiment Station at Annapolis, Maryland. Like the Wyld motor, it performed well, but indicated the need for improved fuel inlet ports. Both of these motors gave results considerably better than any other motors tested by the organization in the long series of test stand runs.

As a result of all this, Wyld outlined a major project: the construction of a sounding rocket, making use of all the information on motors, aerodynamic design, fuels, parachutes, gyrocontrols and rocket construction the members of the society had acquired through nearly ten years of testing and experiment.

Work began on this rocket in 1939 (see FIG. 17), but it was not to be completed. The war was at hand, and the principal members of the society, Wyld among them, were called upon for experiments and research of another kind. The members of the organization are now widely scattered, and many of them are in key positions in the various fields of military rocketry. In 1941, at the suggestion of military authorities, the society

temporarily suspended its regular public meetings, as a means of helping to preserve the secrecy with which the Allied nations had begun to cloak the subject of rocket research.

Though its principal members are still heavily engaged in wartime work, the society continues to publish *Astronautics* (now *The Journal* of the American Rocket Society), and is planning to resume its experimental work and regular meetings as soon as conditions will permit. Of all the pioneer rocket societies of the world—and before the war there were at least a dozen in existence[3]—it appears to have been the only major one to survive.

[3] These included the British Interplanetary Society, founded in 1933; the California Rocket Society, founded in 1941; the Cleveland Rocket Society, founded in 1934; the Galcit (Guggenheim Aeronautical Laboratory of the California Institute of Technology) Rocket Research Group, founded in 1936; the Indian Rocket Air Mail Society, founded in 1936; the Nederlandsee Rakettenbouw (Holland), founded in 1935; the Peoria Rocket Association, founded in 1934; also organized groups in Russia, Japan and Australia.

Chapter X

The Sword of Fire

1.

"THE ROCKET," said Sir William Congreve in 1807, "is in truth an arm by which the whole system of military tactics is destined to be changed."

Long before the actual conflict, there was evidence that the second World War, unlike the first, would make considerable use of rockets. Vague stories of new experiments in military rocketry began to come out of Europe as early as 1930. The forerunnners of the Katusha, the *Nebelwerfer* and Z-gun were even then turning over in somebody's mind.

A United Press item from Paris, on June 14 of that year, playfully declared that "the next war should prove the delight of small boys, for it will be fought in part with skyrockets." The military engineers of France, Italy and Germany were said already to be experimenting with "highly explosive skyrockets" in an effort to find some means of propelling explosives without using cannon.

The reasons were fairly apparent. The gun was no longer an adequate defense against the tank or the bombing airplane. Attack upon armored vehicles requires some sort of missile which has enormous striking power and fairly flat trajectory, and above all, one that can be shot from a gun or launcher light and quick in movement.

Against airplanes, fast projectiles capable of great altitude and speed are needed for the ground defense. In plane-to-plane fighting, the ordinary gun has a practical upper limit in size and firepower. In large guns the recoil is enormous. To take it up on the plane requires heavy equipment that can be carried only at the expense of payload, bombs, crew space or cruising range.

It is no surprise therefore that inventors were early proposing

"torpedo rockets" for use against attacking airplanes. The British inventor, Harry Grindell Matthews, a pioneer in the development of talking pictures and radio-controlled aircraft, was one of the first. In 1938 he announced the development of a liquid-fuel rocket capable of "throwing an aerial minefield into the sky around London and other cities vulnerable to air attack."

Matthews' proposed rockets were 12 to 15 feet long, and two and a half feet in diameter, with gyroscopic control and stabilizing fins. At pre-set altitudes they were to throw out a succession of parachutes, from which would trail lengths of specially prepared wire to entangle the propellers of attacking planes. He visualized such rockets as capable of carrying as many as fifteen parachutes, each trailing 1,000 feet of wire. Each rocket might thus be able to guard about a square mile of area, for a period of 15 minutes, or so long as the wire could be made to remain in the air.

Antiaircraft rockets like that, the inventor confidently told newsmen two years before the beginning of the second World War, "will be the greatest possible deterrent to aggression and aggressor states. The rocket will give the defense such an advantage over the offense—especially in the case of Britain—that perhaps when men see war is useless they will not resort to it."

2.

A year after Harry Grindell Matthews' announcement in England, the progressive American journal *Army Ordnance* carried a well-thought-out and prophetic article on rockets in war. It was written by an officer in the U. S. Army Reserve, Major James R. Randolph, and appeared in the summer of 1939.

Major Randolph, calling attention to the war-rocket experiments of Dr. Goddard in World War I, set forth the possibilities of military rockets in terms of approval and enthusiasm. "There probably would be no great difficulty in equalling with rockets the performance of the German long-range gun that bombarded Paris from a distance of 75 miles (in 1918)," he wrote. "But instead of firing shots of moderate calibre[1] at long

[1] The Paris gun fired shells of about 8-inch caliber, each weighing a little over 700 pounds. A 24-inch shell of similar proportions would weigh almost 4 tons. The German "V-2" rockets of World War II had a diameter of more than 5 feet, and a starting weight of above 12 tons.

intervals a rocket plant could fire the equivalent of 24-inch shells about as fast as desired. Such a job would be no more ahead of present practices than war-time bombing raids were ahead of the airplane of 1913."

The practical range of such bombarding rockets could, he pointed out, be much greater than that of any imaginable gun, and theoretically at least would be quite capable of shooting across the ocean. The practical limits would be the enormous cost of such super-rockets, and the difficulty of hitting the target. Even at 75 miles, Paris proved a difficult mark for the German gunners to hit. Rockets, unless guided by some correcting device, would be even less accurate than such a gun. Consequently, for very long bombardment by rocket, Major Randolph suggested that human pilots might be required.

Shorter-range rockets might find almost innumerable uses in warfare, he declared: for bombardment, for coast defense, for use against large ships by submarines and other small craft; and especially for infantry attack.

> The fact that the rocket's firing device would probably cost less than one per cent of the cost of an equivalent cannon [he wrote] would enable a much larger number to be fired at once—and certain other characteristics of the rocket would require it.
>
> When a fortified position is to be reduced by cannon, the bombardment often lasts for several days, giving the enemy ample time to bring up reenforcements. With rockets, the whole artillery preparation would probably be shot off at once, or in several volleys.
>
> The enemy would think himself safe in a quiet sector; his men would be out of their shelters and off their guard; then suddenly a whole bombardment of rockets would come plunging down on them, followed immediately by the attack.

3.

Barring the transoceanic and pilot-carrying rockets postulated by Major Randolph—and they may yet appear!—virtually every military service predicted for rockets by the writers and engineers of the thirties were actually assigned to them successfully in the second World War:

For a time they were among the war's most secret weapons. The British were using rockets in defense of London, the Germans were using them against Malta, the Americans were in the last stages of developing the bazooka long before the world knew anything about it.

The Russians kept the pact of silence so well that when they began using antitank and anti-personnel rockets before Moscow and at Stalingrad the Germans were unable to figure out what sort of missiles were coming against them. The surviving pilots of Stuka bombers, blasted in mid-dive by salvos of rockets, complained of the "fiendish weapons" of their Russian adversaries.

The earliest and most famous of the Russian weapons was the Katusha. The first pictures to reach this country were in a Russian propaganda film, "The Defense of Stalingrad," released early in 1943. Fleeting glimpses of the weapon in the picture, and photos from the film subsequently issued by Sovfoto, disclosed the Katusha to be about six feet long, four to six inches in diameter, and virtually the same diameter from front to rear, except for a sharply pointed nose. The rocket was powered by dry fuels.

Katusha rockets were fired in enormous numbers, from two types of launchers. The ground launchers were racks carrying six to eight rockets each, arranged in rows to provide tremendous firepower. The rockets were launched by remote control.

The second type of Katusha launcher was mounted on trucks. In early versions, the firing apparatus held 42 projectiles arranged in superimposed rows. These trucks could be driven rapidly toward the enemy, hub to hub, and the rockets fired automatically, singly or in salvos, shooting in a high trajectory. They produced terrific concentration of firepower on an advancing enemy armored column, or struck his attacking forces with shattering effect.

American war correspondents first saw the Katusha in action in July, 1944, when the Russians were hammering the retreating Germans around Minsk with rocket bombardment and showers of propaganda leaflets. The leaflets were dropped from planes. The rockets were being used in the woods and forests to provide a more potent form of persuasion. The rocket guns viewed by the correspondents were mounted in eight double racks, so that

16 blazing projectiles flew out of each truck at a salvo. The writers were interested to note that though the rockets were secret, there was no secret about the trucks at all: they were American, mostly Studebakers.

In the Minsk battles the rockets not only burst like shrapnel, but also threw a spray of hot flame over the target—somewhat in the manner of flame throwers.

Another type of Russian rocket launcher was the multi-barreled "howitzer," which in some versions consisted of thirty launching barrels mounted on a two-wheeled truck. It could be moved rapidly, wheeled and aimed swiftly, and could fire like a giant shotgun, launching all thirty projectiles at once at an approaching tank or armored column.

The Russians also developed an antiaircraft rocket which, like the rocket proposed by Grindell Matthews, ejected a parachute and a tail of wire. Their most effective rocket weapon, from the point of view of penetration, was the "upside-down bomb" originally designed for use against tanks and armored vehicels, and launched from Illuchin Stormovik ground-attack planes. These rocket bombs were slung on launching rails under the wings, and were aimed simply by aiming the craft itself. The early models, effectively used against the Germans as early as November, 1941, in the defense of Moscow, weighed 220 pounds, and were propelled by an 11-pound charge of black powder.

Since the impact and penetration of a bomb depends on its velocity—and increases as the *square* of the speed—the gain in penetration from the added boost of the rocket is very large. From this small additional charge the Stormovik rocket bomb's velocity on arrival could be virtually doubled—increasing the impact by four times: sufficient usually to crack a tank open like an eggshell. The explosive charge of the bomb could then go off inside, leaving only a shattered hulk.

The Russians used these rocket bombs with such effectiveness in 1941 and 1942 that the German tankmen renamed the Stormovik plane *der schwarze Tod*—the Black Death.

4.

Whether the Germans, like the Russians, had long been secretly experimenting with military rockets is a question at

present unanswerable. If not, they were quick to copy foreign examples. The Russians began using their Stormovik rocket bomb about November, 1941. Within a few months the Germans were using a bomb of similar type, with somewhat greater penetration, in the bombing of Malta: It was their plan, fortunately unsuccessful, to use the extra impact of rocket bombs to destroy the underground installations of the island.

The Germans also quickly copied, or adapted, the multi-barreled antitank and anti-personnel rocket gun. Instead of using thirty barrels, the German "mortar" generally had six barrels mounted in a circle, like the cylinder of a revolver. This contrivance, called a *Nebelwerfer* ("fog thrower") was mounted on the standard German 37 millimeter antitank gun carriage, and had a sustained rate of fire of 60 rounds a minute.

The stubby barrels were only a little longer than the six-inch rockets fired from them. The projectiles were loaded into the barrels from the rear, where they were held by a clamp until ready to fire. The firing was by electrical contact, setting up a circuit through a wire embedded in the propellant charge.

The *Nebelwerfer* apparently was not capable of salvo discharge but could fire the six rockets in very rapid succession, producing almost the same effect. Each projectile weighed about 50 pounds, and had an extreme range of 6,000 yards—about three and a half miles. The weapon was usually employed at shorter ranges, however; about two miles being the best practical distance. The rockets were lobbed high and came down at a steep angle, accompanied by a weird whistling noise which was most uncomfortable to hear, particularly near the receiving end of the trajectory. American soldiers who encountered great numbers of them in Italy and later in France, called them "screaming meemies."

The German anti-personnel rockets were shaped like huge potato mashers, with a warhead at the front sometimes as much as twelve inches in diameter and two or three feet long. A narrower portion behind, like the handle of the masher, contained the propellant charge, the nozzle, and carried a hooplike guiding fin. The over-all length of the large ones was nearly six feet. The rockets were fired from racks, some holding as many as six rockets. In one type, the case in which the rocket was shipped from the factory also served as the field launching rack. It was

provided with guide rails inside the crate, and could be leaned against a pile of earth, or placed at a suitable inclination in a hole or against a fence, wall or hedge, and fired.

The German airplane rocket weapon proved particularly serious. In one air battle over Schweinfurt, the ball-bearing center of Germany, in January, 1944, Nazi fighters equipped with rockets succeeded in breaking up a huge formation of American bombers and destroyed sixty of them; one of the greatest single losses sustained by an American air fleet.

The German airplane rockets were fired from several types of German planes, notably Messerschmitt-110 twin-engined fighters. The launching rails were carried under the wings. The practice of the Germans in the Schweinfurt and subsequent air battles was to fly mass formations of rocket-bearing Me-110's alongside our formations, just outside the range of our defensive guns. When in proper position, the Me-110's suddenly skidded into a new formation facing our bombers, holding a line almost wing to wing. They then let go their rockets, usually in two salvos, pouring them into the bomber formations. The effect was frequently to cause the bombers to scatter, whereupon swarms of German fighters attacked them singly with conventional weapons.

After one such battle with German rocket-carrying fighters early in 1944, Sergeant Ernest W. Clauser, of Duncannon, Pennsylvania, a ball turret gunner, described the fight[2] in this way:

> On our first run over the target we were all by ourselves. There wasn't even any flak. Then, off in the distance, we saw 18 ships. They were stacked in a neat Fortress-type formation and for a moment we were relieved because we thought some reenforcements were on the way.
>
> They circled in formation and then we saw that they were Messerschmitts-110. They got around to the side of us and then they did the neatest "right-into-the-line" movement you ever saw. When all of them were facing us, they let go a broadside of rockets. The rockets seemed to burst in a great line of red and yellow fire. The whole mass of rockets flew into our formation. Most of them missed, but some of them got lucky hits. We felt like we were fighting from flying pill boxes and those Messerschmitts were infantry coming over the top.

[2] Quoted from the United Press.

Off Italy, our ships were subjected to many savage attacks by German aircraft armed with rockets. Quentin Reynolds, of *Collier's*, describing one such attack, declared he had seen a rocket bomb hit the cruiser "Savannah" in the Bay of Salerno, "and it traveled so fast that none of us heard its scream."

5.

Despite these spectacular weapons of the Germans and Russians, to the British must go the credit for one of the most effective rocket weapons of the second World War. The British antiaircraft rocket, modestly referred to as the UP (for "unrotative projectile"), was fortunately developed by Britain before the beginning of the great "blitz," and was used with remarkable effect in the summer and autumn of 1940.

The British, following Dunkirk, had found themselves virtually without guns, without ammunition, with few airplanes, and almost defenseless against their enemies. The rapidity and cheapness with which rockets could be manufactured and launched, and the high altitudes and enormous concentrations of firepower they could achieve, played a major part in saving London from complete destruction by air.

The British UP rockets were, in their way, rather spectacular weapons. They were about four feet long, some three inches in diameter, and carried an explosive charge almost as great as that of a three-inch shell. They were propelled by cordite, and were shot from launching racks of various designs, many of which in the early part of the war were improvised from iron pipe, rails and the like.

The noise they made, and their awesome trails of fire, were such as to send the battle-blasé British scurrying to shelters, even after the blast of ordinary antiaircraft guns no longer had the power to stir them. This was partly due to the sound, and partly to the long steel splinters which the first antiaircraft rockets showered down on the defended area after exploding in the sky.

> You've probably heard what a frightful noise the new rocket guns in London make[wrote Ernie Pyle,[3] who visited London in May, 1944]. At least I'd heard about it before

[3] Quoted by permission of the Scripps-Howard Newspapers and United Features Syndicate, Inc.

> coming up here. . . . I think that I was so afraid to hear the awful noise of those rocket guns that I was practically paralyzed. Finally, they did go off. . . . The noise itself isn't so bad . . . it's what it sounds like that terrifies you. For a rocket going up sounds like a bomb coming down. After you've learned that and adjusted yourself to it, the rocket guns aren't bad.

The UP rockets were shot from several types of launchers, one of them the famous "Z-gun." This was a fixed mounting device capable of rotating on its base, permitting change of elevation of the rocket at launching by swiveling the launcher up and down. The whole contrivance rather resembled a somewhat grotesque old-fashioned altazimuth telescope. The Z-guns held two rockets each, and were fired by remote control. Two operators were assigned to each gun, to load and aim, and each operator was provided with a roofed-over shelter for protection during fire.

Another launcher used by the British was somewhat like the mobile Katusha launchers of the Russians. Mounted on trucks, amphibious jeeps and special rocket-projectile vehicles, these launchers held six rockets each, and could be fired singly or in salvos.

British antiaircraft rockets were the result of more than seven years of research in Great Britain, the West Indies and in the United States. Research was officially begun by the British army in 1934, when word came to England that the Germans were showing considerable interest in the development of military rockets at Spandau.

By 1938 the first projectiles were ready for testing, and a site for field experimentation which would be secure from prying eyes was selected in Jamaica, West Indies. There, in the spring of 1939, the first of them were fired, only a few months before Hitler's troops marched into Poland at the beginning of the war. The next problem was to iron out the manufacturing kinks and develop better ways of making the rocket propellant. This was finally produced in extruded form, in powder mills operated by remote control. Manufacture of propellant and rockets was commenced in 1940.

Al Newman, a writer for *Newsweek*, witnessed a special demonstration of the Z-gun, and wrote:

> The gun is a strange, barrel-less device. The shells are bigger than I had thought, and they have much longer cases than ordinary artillery ammunition because of the huge propellant charge that is required. There is a shield on each weapon to protect the two members of the crew from the terrific back-flash. In the shield itself are small dimmed-out lights by which they set dials for elevation and direction and adjust fuses for the altitude of the burst.
>
> All commands are transmitted electrically by small loud-speakers at each gun so that the entire battery is centrally controlled. The firing is simultaneous and done electrically from the control room. One man presses a button to set off the entire battery, and I hope they make him pay for the privilege because it must be more fun than anything else in this war. . . .
>
> People were beginning to shout "Ready" so we cleared off back to the road with the rest of the group. Now more dim lights were flashing on, and there were more shouts as firing data was received and complied with, and the clank of metal as the guns swiveled around and elevated and the projectiles were laid on their rails.
>
> "Fire." There was one of those bad, brief silences. Swoosh! Everything lit up in white flaming streaks, and you could smell cordite and feel the light ash of the propellant dust on your upturned face. Five second went by before the clouds lit up with multiple flashes as the shells exploded. Seconds later their drumfire noise came down like a string of giant cannon crackers going off.
>
> The reaction of the press representatives was unusually unanimous. They moved back 10 feet and said "Jeez."

The man chiefly responsible for the development of the "Z-gun" and its rockets was Alwyn Douglas Crow, until 1936 director of ballistic research at the British army's Woolwich arsenal. Asked to find a team to explore the possibilities of rocket guns, he retired with a hand-picked crew of physicists, engineers and mathematicians, first to a remote hilltop in England, and later to secluded island beaches. At one stage he faced the barrage of his own guns, flying an old biplane to determine whether or not the rockets were attaining the height theoretically called for. Until the barrage rockets were taken off the secret list, he was referred to by associates as "Mr. Z." He now keeps cigars in a metal box made from the first German plane, a Junker 88, shot down by rockets over England.

6.

On May 26, 1944, Air Chief Marshal Sir Sholto Douglas, commander of the Royal Air Force Coastal Command, disclosed that the British and Americans had developed still another rocket weapon; this one to prove the equivalent of cannon fire for aircraft. The air arm had named it the RP, presumably for "rocket projectile."

It was first used early in 1943 and by 1944 had been employed with considerable success by both the British and Americans in attacks on enemy shipping, naval vessels and submarines.

As a matter of fact, it was a successful attack by carrier-based American planes on a submarine in April, 1944, that "broke" the story. The planes were piloted respectively by Lieutenant (j.g.) Leonard D. Ford, of Seaford, Delaware, and Lieutenant (j.g.) Willis D. Seeley, of Huntington, Indiana. Shooting their rockets, they scored three definite hits and four probables, beginning the shooting from extreme range. The submarine appeared to be heavily damaged and began circling, throwing up a terrific anti-aircraft fire. The planes dashed in and finished it, and Lieutenants Ford and Seeley were thus the first pilots in the world to knock out a submarine with the assistance of rocket power.

Several types of British and American planes had by that time been equipped with rocket launchers, notably the twin-engined Beaufighter, the single-motor Typhoon, and the American Avenger.

These craft carried four launching rails under each wing, so adjusted that the rockets could be fired in pairs, or all eight rockets could be fired as a salvo. Royal Air Forces flyers were exceptionally proud of their new weapon, and some declared that a rocket salvo from a Beaufighter "hit like six-inch naval guns" and were far deadlier than ordinary bombs. Said one: "My salvo blew the whole stern away from one ship I attacked. I had to weave plenty to get out of the way of chunks of ship that came up at me."

The RP rockets were about four feet in length, some three inches in diameter, and equipped at the tail with four squarish fins, each about six inches long. The propellant was cordite, ignited electrically from the cockpit by a small fuse wire embedded in the charge. These rockets were used extensively not

only in British home waters and along the coast of France, but also in the Aegean and Atlantic, and over land in low-level attacks against bridges, gun emplacements, radio stations and troop concentrations.

In July, 1944, rocket-firing Hurricanes of the Royal Air Force Coastal Command in the Adriatic sank the former Italian liner *Italia*, which had been converted into a cargo and troop transport by the Germans. A little later in the same month a fleet of 40 enemy merchantmen was reduced to a flaming mass of wreckage off Helgoland by Beaufighters using rockets, torpedoes and cannon. In September of 1944, RAF Beaufighters destroyed the former Italian liner, *Rex*, in Trieste Harbor, with a total of 123 rocket hits.

7.

The first major announcement of a strictly American rocket weapon came on March 27, 1943, when Major General Levin H. Campbell, Chief of Ordnance of the U. S. Army, disclosed in an address at Cincinnati the development of the now-famous "bazooka" officially known as "Launcher, Rocket, AT,M-1." This weapon, which had gone through a period of preliminary development, was released for manufacture in May, 1942, and within thirty days several thousand had been delivered to the armed forces for field testing.[4]

The early standard field models of the bazooka were 54 inches in length, and two and a half inches in diameter. They were electrically fired, by means of a trigger-like switch. Electricity for the job was provided by two small batteries carried in the stock. Unlike a rifle, the bazooka is dangerous at both ends, for the tail blast can burn a man at twenty-five feet. Consequently the weapon must be rested across the shoulder of the gunner, and the sights are placed on the side.

The bazooka is properly called revolutionary, for it gives the infantryman a weapon with the punch of heavy artillery, yet weighs less than a rifle. It costs less than $20 to manufacture, and

[4] Major credit for launching the whole modern program of military rocket development in the United States goes to Col. L. A. Skinner of the U. S. Army Ordnance Department who began work on a small scale at Aberdeen Proving Ground as early as 1932. The basic data and experience he obtained made possible the rapid development that followed inauguration of large-scale research at Aberdeen in 1942.

under proper circumstances it can do the job of a 155 millimeter howitzer that costs $25,000. Most important of all to a man in battle, it is as maneuverable as a rifle, and in the words of Major General Campbell, "any foot soldier using it can stand his ground with the certain knowledge that he is the master of any tank which may attack him."

The bazooka projectile is propelled by cordite, so arranged that all of the burning takes place within the tube of the launcher itself. This rapid acceleration gives the projectile an almost flat trajectory, but not a particularly long range. The bazooka is essentially a point-blank weapon; it is used against tanks and other objectives from ambush, or from cover close in. Its accuracy at a distance is bad, though many soldiers have been able to develop high proficiency with it.

In the early models, the propellant did not always complete its burning inside the launcher tube. Consequently, the gunner was required to use heavy gloves and a face mask to protect himself against residual blast from the projectile as it left the chamber. In later models, a wire screen was placed around the muzzle of the projector, like the large end of a funnel. The screen permits the gunner to sight through it, but damps the back-blast sufficiently to make cumbersome mask and gloves unnecessary.

The bazooka proved an immediately popular weapon with the Army. Many minor improvements were suggested and rapidly incorporated into it. The original sights were open. A soldier in Africa suggested a method of producing closed sights. The drawings were flown to the United States; manufacturers went to work, and within twenty days a supply of the new closed sights was back in Africa, for the use of gunners who requested them.

Stories of the sometimes amazing exploits of the bazooka projectile are almost innumerable. Major General Campbell himself told how, during the early operations of the American Army in Africa, one lone soldier was able to wade ashore, get into favorable position before a small fort which had been giving the landing party considerable trouble, and with a single shot demolish it. In another instance, an American soldier was surprised by six big German tanks. He hid himself in a hole and fired hastily at the leading tank from this cover. In his excitement he missed the tank, but the projectile struck a large tree and felled it. The tank commander thereupon surrendered. He

was amazed to find he had not been attacked by heavy artillery.

The Germans, who copied the weapons of most of their adversaries in the war, also copied the bazooka, but at first without too much success. The early German version, which presented an outward appearance almost identical with the American weapon, was a bit too large: it shot a projectile nearly four inches in diameter, instead of the more practical two-and-a-half-inch projectile of the American product. This enlargement made the gun too cumbersome to handle easily. Another difficulty which the Germans did not readily overcome was that of producing a safe and practical propellant. The German bazookas captured by our troops were uncertain in action; the rockets were liable to explode in the launcher.

8.

The part played by the rocket in the Allied invasion of Europe in June, 1944, is an example of the rapidity with which a mechanical art can be developed when there is money, will and energy behind it, backed by the imagination and skill of trained engineers and experimenters.

In the decade before the beginning of the second World War there probably was not spent as much as $150,000 for rocket experimentation in all of the countries of Europe and North America. Only a handful of men took part, and most of these had no financial backing at all.

In the four years following the beginning of hostilities, well over a billion dollars were spent for rockets and rocket development by the British and Americans alone. In 1944 it was disclosed that the United States Navy was using $100,000,000 worth of rockets *per month*. Additional untold wealth was poured into this work by the Russians. The Germans devoted a major slice of their war budget to it. Under such circumstances, it is no wonder that war rockets were rapidly developed.

In the United States even antiaircraft gunners were trained with the aid of rockets. Rocket targets were developed with exaggerated fins at which gunners could shoot under conditions closely simulating the excitements, velocities and unexpected motions of actual aerial combat.

The rocket targets were powered by dry fuels, and were

about five feet long and three inches in diameter. Each was equipped with three large guide-fins. At Camp Davis, North Carolina such rocket targets, 59 inches across and moving at speeds up to 450 miles an hour, were in continual use in training. At night the targets were lighted by searchlights.

In 1944 the United States Army developed still another type of rocket, a barrage rocket with a light enough launcher to be easily portable; simple enough so that the launcher and rockets could be used on beachheads, carried in gliders, or dropped behind the lines for the relief of parachute troops or detachments of infantry cut off by the enemy.

The projectiles weighed less than fifty pounds, produced destructive effects comparable to those of a four-and-a-half-inch shell, and were sufficiently mobile so that paratroopers could carry both rockets and launchers on their backs during invasion of enemy territory. By mid-June, 1944, it was disclosed that more than a million of these new rockets, details of which are still unavailable, had been shot on various fronts in the war. Orders for "many millions more" had been placed with manufacturers.

In the Pacific, rockets on navy aircraft were being widely used for strafing surface vessels and submarines—and in the case of torpedo bombers, for clearing the decks of attacked ships and barges upon beginning their torpedo run. On May 14, 1944, 40 Japanese ships and barges were destroyed in the harbor at Rabaul, New Britain, by rocket planes. Earlier, in a small raid at the same place, rocket-bearing fighters damaged or sank 12 Japanese ships. By mid-1944, the Navy disclosed, at least six types of American aircraft were carrying rockets as regular armament. On the Navy craft the rockets were carried on separate launching rails, as with the British, four under each wing.

The U. S. Army Air Force was meanwhile developing its own rockets. The first of these were tried out over Aberdeen Proving Ground on July 6, 1942, on which occasion Lieutenant Colonel H. L. Donicht, of the Materiel Command's Armament Laboratory, fired the first rockets. Subsequent research developed the three-barreled underwing rocket launcher which became standard equipment for American Air Force fighters and bombers.

The standard army airborne rocket projectile is four and half inches in diameter, and is thus about the size of a 105-millimeter shell. It is three feet long, a third of the length consisting of the high-explosive warhead and the fuse. The remainder of the interior space is occupied by the, propellant, a form of cordite specially compounded for rockets and extruded in proper shape for insertion into the rocket barrel. The nozzle, at the rear, is about six inches long and an inch and a half in diameter. The entire rocket case is of steel.

Less slender than the British and early navy rockets, the AAF rocket looks rather like an elongated artillery shell, with a sort of pinched-in "handle" at the rear, where the nozzle is attached. Encircling the nozzle's end is a ring carrying six small fins, each about four inches long and an inch wide hinged so they can be folded forward against the sides of the nozzle when inserted into the launcher tube. (See Plate VI.)

The fins remain in the folded position until the rocket leaves the tube, whereupon they straighten up into a fan of small blades to keep the projectile on course. The rockets are electrically fired, a fire-setting device enabling the pilot to shoot in salvos or "in train"—that is, in series, with the projectiles leaving their launchers at intervals of one-tenth of a second.

The launchers for these rockets are simply tubes of paper and plastic. The combined weight of the six launching tubes carried by an airplane (two three-tube clusters) and their rockets is about 450 pounds. A 105-millimeter howitzer of the same caliber, with six shells, weighs about 4,000 pounds; ten times as much for the same firepower.

Lieutenant Colonel Donicht, writing in *Air Force* for August, 1944, remarked that potentially, a single fighter pilot flying a Thunderbolt with its eight .50 caliber wing guns and six rocket tubes "in a single strike has the firepower of six armored forces tank busters . . . the rocket gun, because it is light and can be applied to fighter aircraft, is the AAF's 'heavy artillery.' "

9.

One of the most spectacular later weapons of the war, and almost a necessary concomitant of every big amphibious attack, was the "rocket ship": a vessel especially equipped to launch

enormous numbers of rockets to clear the beaches ahead of the landing barges. Though the ancestry of this device goes back to Congreve and the British naval attack on Boulogne in 1806, both the vessel and its rockets were among the most modern of World War II weapons. The development was originally undertaken as a result of lessons learned in the disastrous raid on Dieppe on August 19 and 20, 1942.

Among the first second World War craft equipped to launch rockets was a small landing boat which the gunnery division of the Royal Navy fitted out with rocket cradles and high-explosive projectiles in the fall of 1942. Tests were carried out with the greatest secrecy, and the results were so promising that shortly after the surrender of the Axis forces in Africa the Royal Navy hopefully converted several tank landing craft into rocket launchers.

It was decided that the invasion of Sicily in September, 1943, would provide a suitable opportunity to try out the new weapon in actual landing operations. From the first shots, the success of the floating rocket launchers—designated as the LCT(R)—was assured. Prisoners taken during the Sicilian operations were awed by the effectiveness of the projectiles. They told Allied military leaders that they had been able to stand up pretty well under ordinary shellfire, but were unable to bear the noise, explosions and destruction of the rockets.

Ordnance and gunnery officials of the United States Navy had also been busy with experiments along the same lines, and in August, 1943, it was decided to pool the efforts of both nations. A number of rocket-equipped British LCT's were turned over to the United States Navy for experiment and training, and with other specially adapted landing craft they were formed into highly effective assault groups to provide protection for troops making landings after bombardment from larger warships.

Subsequent U. S. Navy LCT(R)'s were mounted on British-made LCT hulls, but the launching devices themselves were adapted to American-made rockets and altered to suit American tactical practices. Each craft carried hundreds of rockets, and the total firepower of one of these ships was equal to about two and a half times the firepower of a battleship of the New Jersey class. Three types of rockets were ordinarily carried. The principal rocket was a high-explosive projectile, capable of tremendous

destruction. The second type was a ranging rocket, filled with an incendiary compound which could be used in determining the accuracy of the range. The third was a smoke rocket used in screening troops.

The rockets were fired electrically, from batteries charged by generators attached to the ships' engines. For safety, the rockets were loaded into racks and fired in salvos, and during an attack the craft fired these salvos so fast each overlapped the previous one, giving an almost continuous stream of fire which eliminated secondary fortifications such as mines, wire, machine-gun nests and shallow pillboxes. The U. S. Navy recently asserted that the rockets would also temporarily stun men in fortifications.

The first large-scale use of the LCT(R)'s, after the experimental tryouts on Sicily, occurred during the invasion of France on June 6, 1944. In the Normandy landings the rocket ships went into action before the first waves of landing craft, working with the battleships, cruisers and destroyers in the great bombardment to neutralize the opposition. Standing offshore with naval shells howling overhead, the rocket craft blazed away with so many salvos that sections of the beaches were dancing infernos of fire and debris.

The rocket ship subsequently became a necessary part of virtually every Pacific landing operation. Rocket launchers have been mounted on a number of different types of craft for specialized uses, ranging all the way from big LCT(R)'s, which are about twice the size of American-built tank landing craft, down to portable launching racks mounted on troop-carrying landing barges and even on amphibious vehicles. The "beach rocket" with which the amphibious craft are equipped is four and a half inches in diameter, and carries the wallop of a 105-millimeter shell. The launcher is merely a framework not much different from those used in firing Fourth of July skyrockets, except that it can be adjusted in elevation.

Chapter XI

"With Ten-fold Fury"

1.

ONE day in 1943, off the coast of Italy, British fighter pilots noted that the German attackers of Allied shipping were using a new kind of weapon—a small glider, to which was attached a bomb. This device, launched from a distance, appeared to be directed from the launching plane by remote control. After it had been maneuvered into attack position, it suddenly seemed to spring to life, hurling itself with force and directness at the target, where it exploded.

The British, with their customary aptness for picturesque and slightly deprecatory phrases, named this device the "Mark I chase-me-Charlie." The weapon in reality was a small glider with a bomb as its body, and it often missed. The launching aircraft needed to be rather near by to guide it properly, hence was vulnerable to attack from fighter planes. The "chase-me-Charlie" consequently turned out to be no major weapon, and the RAF and Royal Navy were principally amused by it.

Had they known, however, that this device was ancestor to clouds of robot bombs later to shower on England, perhaps there would not have been so much merriment. For the Germans, in developing some sort of flying torpedo, projected many variant forms, trying out several in combat before selecting the types which gave promise of success. The robot[1] bomb of the Germans, later nicknamed the "buzz-bomb," the "bumble-bomb," the "doodlebug," the "blastard" and the "whizzbang" by the British, and referred to by the Germans as the *dynamitmeteore* ("dynamite meteor"), the "Wuwa" (for *Wunderwaffe*, or "won-

[1] Properly pronounced "rubbut." The word is of Czech or Polish origin, and means "worker" or "laborer." It was introduced into English about 1921 by Karel Capek, a Czech playwright, in the drama "R.U.R." (for "Rossum's Universal Robots").

der weapon"), and the "V-I" (for *Vergeltungswaffe Eins*, or "Vengeance Weapon, No. 1") was no insignificant addition to the armamentum of air war. It is something indeed for future war leaders to worry about.

Crude as the first German models were, and unreliable as to direction and performance (though this was by no means so bad as reported), they nevertheless blitzed England as she had not been hammered since the aerial attacks of September, 1940. Children and the aged were evacuated from London. A great many Allied fighters and bombers, sorely needed elsewhere, were forced to devote themselves to the task of dropping thousands of tons of bombs on robot-bomb launching places in the Pas de Calais area of France and later in Belgium from whence many of the flying torpedoes were coming. Though the Allies admittedly knew about the robot bombs nearly a year before the first of them were launched, they were unable to devise any fully effective defense against them, and the menace in fact was not ended until land operations had overrun and captured all the launching places within range of England.

2.

Perhaps the most amazing thing about the German buzz-bombs was their simplicity. Like the smaller "chase-me-Charlie," the buzz-bomb was essentially a light glider, with a charge of explosive in its body, a steering mechanism, and a jet engine. However, the buzz-bomb had no equipment for remote control but went forth under its own control toward a target at which it was aimed from the launching runway more than 100 miles away. It moved by jet propulsion throughout its flight.

There appear to have been a number of slightly differing types; some carrying incendiary charges instead of demolition bombs. The majority were square-winged, with a wingspread of about 16 feet and a body 25 feet long. The elevators were unusually long, almost making a pair of secondary wings behind. Elevators and rudder were both controlled by servo-motors operating on compressed air.

The torpedo-shaped body housed a device for setting off the charge, a warhead containing slightly more than a ton of explosive, a cylindrical gasoline tank carrying about 130 gallons of

fuel, two light spherical wire-wound pressure tanks filled with compressed air, a simple air-operated gyro-pilot and a servo-mechanism actuated by the gyro-pilot which steered the craft.

In addition, many carried small radio transmitters in the nose, capable of emitting a continuous short-wave radio tone, enabling triangulation stations on the coast of France accurately to

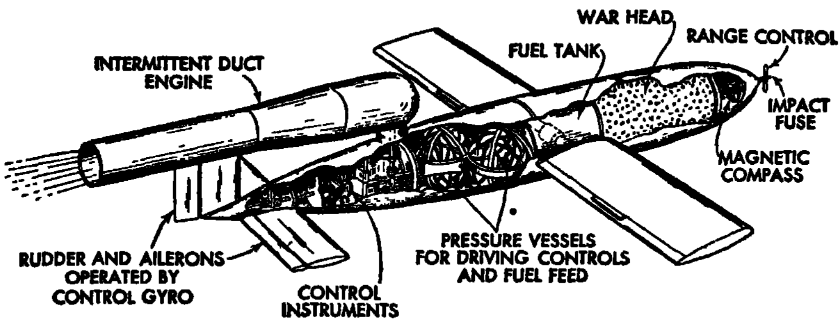


FIG. 18. Plan on the German "buzz-bomb" or robot bomb.

keep track of the exact course of flight and determine the landing point within an area of only a few city blocks. By this means, subsequent bombs could be adjusted to correct the aim.[2] The flight of each bomb is also believed to have been followed some of the way by radar.

The entire body of the robot was made of thin steel sheet, lightly braced. The wing was mounted on a tubular steel main spar which passed through the fuel tank and out on each side to a point near the wingtip. On this were mounted a series of pressed steel ribs, covered with light sheet steel.

The two spherical compressed-air bottles were ingeniously employed. Wire-bound to combine strength with lightness, one provided pressure to force the gasoline into the jet engine. The other enabled the gyros and the servo-mechanism to steer the craft.

This construction all showed remarkable ingenuity, but the most surprising item of all—and the real contribution of the weapon so far as jet propulsion is concerned—was the engine itself. The British identified this, in their early releases, as an "impulse duct engine." It contained no air compressor, no rotating parts, yet it used atmospheric oxygen as oxidizer and other-

[2] It was this small radio set that confused observers and gave rise to early reports that the bombs were radio-controlled.

wise fulfilled the requirements of a true airstream engine. It was, in fact, the first practical example of what is now known as an intermittent duct engine.

It consisted principally of a large tube about eleven feet long, slightly reduced in diameter about midway of its length. The bigger end, pointing in the direction of flight, was covered by a light grill in which were about three hundred square openings, somewhat resembling the air orifices of a harmonica. Inside these openings in the grill were spring-steel flutter valves, each about twice the size of a thin razor blade and normally closed. The pressure of the air at the front during flight, however, could push them open. Passing through the grill and into the large interior chamber were nine fuel injection ports. There was also a spark plug for starting the ignition.

The jet engine was mounted above the body of the flying bomb, at the rear, over the rudder. Its thrust was applied through the rudder standard and a brace at the forward part of the engine. This placement served to balance the craft and provide an unimpeded supply of air.

The arrangement of these parts will readily be seen in this schematic diagram.

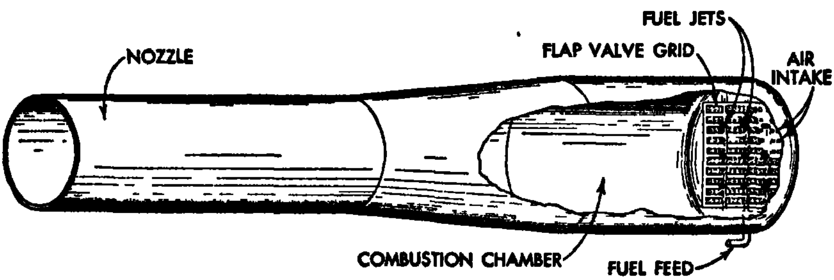


FIG. 19. The German "buzz-bomb" engine.

The craft is moving in the direction of the air intake, at between 250 and 400 miles an hour. Air passes through the grill blowing open its small spring shutters, and enters the combustion chamber. Fuel is spurted into the chamber through the feed nozzles and in the beginning is ignited by a spark plug. The blast throws shut the spring-controlled shutters, and sends a jet of gas out the tail-pipe. Following the blast, there is a partial vacuum left in the combustion chamber, which draws open the shutters,

admitting a fresh charge of moving air, and the process is repeated.

This intermittent action, fast enough to produce a steady purring or throbbing sound, caused early spectators to compare the noise with that of washing machines and similar gear-driven devices. The ingenious little engine obviously was almost as simple as a liquid-fuel rocket motor, having as moving parts only the air shutters. The fuel, once turned on, flows continuously. There isn't need even for the spark plug after the first few explosions; enough flame remains after each blast to furnish ignition for the next.

3.

This engine obviously is related to several of the airstream engines suggested before the war, particularly the intermittent jet engines proposed by Schmidt and Goldau. (See Chapter IV.) Prewar calculations had led to the erroneous conclusion that such engines could not operate unless moving at nearly the speed of sound, but the Germans succeeded in getting the robot-bomb engine to work at velocities of between 250 and 450 miles an hour.

The robot bombs were launched upward at a long angle, after being pre-set in their course by adjusting and starting the gyro-control mechanism. Some launching installations apparently employed powder-driven or compressed-air catapults, while others reportedly shot the bombs into the air by means of rocket-driven launching cars, powered either by dry fuels or liquid-fuel thrustor motors burning hydrogen peroxide and a hydrocarbon.[3] To provide the hydrogen peroxide, the Germans built large plants near Peenemunde, on the Baltic.

The launching speed of the robot bombs was about 250 miles an hour. The engines provided steady acceleration for the craft all the way from launching to destination, so that while they started at something like 250 miles an hour, they ended at 400 or 450. Accordingly it was much easier to knock them out of the air in the early part of the flight than later, when they were extremely hard to catch. The flight distance was regulated both by

[3] Following the liberation of France in the autumn of 1944, the Nazis continued to launch a few robot bombs against England from aircraft over the Channel.

the gasoline load and a small adjustable air-flow measuring device at the nose, a tiny windmill. The altitude was controlled by another adjustable element, which enabled the bombs to fly steadily at almost any height from 1,500 feet up to about 5,000.

The engine starting apparently was automatic, once the bomb got under way with enough speed to blow the air valves open at the front of the motor. Similar valves simultaneously turned on the gasoline, started the spark, and began the rhythmic cycle of explosions, which occurred at better than forty a second—the rate of the explosions being established by the natural resonance of the tube.

Fuel consumption was about a mile to the gallon. In flight the bombs usually held their altitude, spitting flame from their exhausts, until the last of the fuel was gone. Then the machine became a simple glider, tilting toward the earth at a sharp angle or falling into a slow spin. Some of the later models went into a long, silent glide, and so were able to strike without warning of any kind. The target, of course, was one of chance, since the guiding mechanism could only give general direction to the flight.

It is notable, however, that the majority of the bombs which reached England and escaped the defensive barriers erected against them actually fell in London, where they were aimed.[4] It was, therefore, not so random a weapon as the first censored newspaper stories from England suggested; probably not a great deal more random than mass night bombing from conventional airplanes. The principal difference, psychologically, was that the threat of destruction from flying torpedoes was continuous, whereas in bombing from aircraft, there were periods of respite during which the population could come out of its shelters, rest and repair the damage.

[4] The defense finally developed by the British consisted of spotting planes over the Channel, which flashed the whereabouts of each bomb as soon as it was sighted, together with an estimate of its probable course and altitude. Fighter planes promptly went out to meet it. Bombs that were not shot down over the water next ran the gamut of an antiaircraft fire zone, behind which was another area where fast fighter planes were ready to continue the attack. Bombs which succeeded in passing through all of these defenses encountered a zone of rocket antiaircraft projectors (Z-guns) and at length came to an area protected by barrage balloons. Despite all these defenses, many got through, particularly at night and in cloudy weather.

4.

The first robot bombs came over England on the night of June 15, 1944. The Germans had saved the weapon as an answer to the Allied invasion of France, which began ten days earlier, on the sixth of June. Had they sent the robot bombs in much larger quantities, they might well have had a major effect on the outcome of the war.

As it was, more than 2,700 were released on England in the first month after the beginning of the invasion. Some 10,000 casualties were caused, including about 2,700 killed, or about one death per bomb. Had the Germans released 100,000 aerial torpedoes on London instead of 2,700, they might virtually have destroyed it.

No doubt there were many reasons why this could not be managed. The Allies were aware of the existence of the weapon, of course, and had repeatedly bombed launching areas. Prime Minister Churchill disclosed in July, 1944, that more than one hundred launching areas had been under heavy bombardment almost continuously for more than nine months before the first attack began.

Another deterrent was the fact that in July, 1943, British secret agents succeeded in locating the main stations near Peenemunde where rocket experimentation was going forward. Beginning in August, 1943, the full strength of the British Bomber Command was sent repeatedly to attack the laboratories and testing grounds. The British later reported that a number of German experimenters were killed, including some of the key personnel.

The invention of the robots has been laid at the door of almost every active prewar rocket experimenter in Germany, probably with little foundation. Most often mentioned were Hermann Oberth, Goldau, who made prewar experiments with reaction motors of the duct-engine type, and Schmidt, who patented a duct engine in 1934.

The Germans themselves disclosed only one name in connection with the robots—that of Anna Reisch, a woman flyer. It appears that in many of the first models the wings would unaccountably come off in flight. After attempts to get at the trouble by other means, it was decided to clear the explosive

compartment and let an observer fly in it to study the problem aloft.

Anna Reisch, chosen because she was small enough to fit into the explosive compartment, made several flights, watching the behavior of the craft's wing through a periscope. After four days the trouble was discovered. The pilot was injured in one of the landings, and for this sacrifice she received the Iron Cross, first class.

5.

The robot bomb and the glider are essentially forms of aircraft, and we must consider them as such in trying to assess their future importance in the age of rocket power. As aircraft, they are subject to the familiar limitations: they probably cannot fly at altitudes much greater than about 40,000 feet; they rely on atmospheric oxygen for the combustion of their fuels, and their speed is conditioned by the resistance of the atmosphere.

But there is something about the jet-propelled glider that powerfully seizes the imagination. For one thing, the structure can be so very light and simple that the cost of production may be only a fraction of that of a piloted airplane. Estimates of the expense of producing the German robot bomb vary considerably, depending on the quantity postulated; but in mass production they probably cost between $1,500 and $2,500 each, exclusive of the explosive. This is not much more than the cost of a one-ton bomb of the ordinary variety intended to be dropped from airplanes.

Further development might reduce both the cost and the weight and permit even larger payloads. The pilotless feature makes it quite unnecessary to provide for the needs of a human being on the flight. This saves weight and space; may make it possible to reach greater altitudes without the need of auxiliary oxygen supplies, pressure cabins or the like, and in consequence could reduce the cost of both construction and operation.

Pilotless bombs of this kind are basically long-range artillery projectiles. They are far less accurate than artillery shells, but make up for it in three ways: they can carry more explosive, have five to ten times the range, and can be shot in enormous numbers. Evidently they are accurate enough to produce confusion and destruction, and cost the attacked nation much bomb-

ing and effort which necessarily must be substracted from military weight elsewhere.

It seems inevitable that robot bombs will grow in importance in future warfare. Though such writers on war aircraft as Major A. P. de Seversky consider them as auxiliary in nature: an adjunct to the long-range bombing plane, others think them more revolutionary: even predict that the bombing plane itself will give way to jet-driven robots in future conflicts.

Major General J. F. C. Fuller, of the British army, writing in *Newsweek*, in July, 1944, declared that:

> It demands no great flight of the imagination to picture . . . rapid evolution in the flying bomb during the next 30 years.
>
> It is self-evident that such a revolution carries with it the doom of the bomber as a piece of long-range artillery and probably also the doom of the cannon in most of its many forms. The method of attack will then be introduced which will enable one nation to wage war on another, a war of maximum annihilation, without moving a man.

William Philip Sims, the war commentator, declared in the New York *World Telegram*:

> Twenty years from now robot bombs weighing 20, 40 or even 100 tons will almost certainly be able to wing their way across the Atlantic and hit any city aimed at. The present robot, like the first planes, is largely experimental. But if Germany and like-minded powers are given half a chance—as they were after the First World War—they will eliminate the bugs. If we go to sleep and let nature take its course, Britain, America and Russia may wake up some bright dawn to a new Pearl Harbor, only this time on a nationwide scale. We might find ourselves smothered, burned and blasted under a rain of bombs compared to which the robots now aimed at southern England would seem like the first hand grenade dropped on Paris.

In assessing robot gliders, however, it is not necessary to assume that they will be used only for destruction. There are many peacetime tasks that pilotless jet-driven airplanes might do well and efficiently.

For example, they could transport mail and express at higher than airplane velocities, and perhaps more cheaply than by conventional craft. Mail-carrying or express-carrying jet-robots

would need better directional controls than those so far developed, but in time of peace this should not be too difficult to manage.

The gyro-control would undoubtedly continue to serve as the principal part of the control equipment, since it is an excellent basic instrument for keeping the craft on course. As auxiliary control equipment, the robots might also carry photocells and chronometers for guiding on the sun or a bright fixed star, or on a string of searchlights planted along the route like the airway beacons of today. Alternative directional equipment might depend on some modification of the principle of television, or most probable of all, upon narrowly-focused shortwave radio beams.

The altitude to which such machines could fly would be limited principally by their structure and the height at which the jet engine could be made to operate. Altitudes up to 40,000 feet and speeds up to 500 or 600 miles an hour do not seem out of the question. If reliable robot ships can be constructed for transatlantic service, it might be possible to send mail across the ocean by robot in five to six hours.

6.

It may then be difficult to keep human passengers from wanting to go along, exclaiming with Friedrich Stamer: "Flight with jet propulsion I consider exceedingly pleasant."

The first steps toward practical passenger-carrying jet gliders may already have been taken—again by the Germans. In August of 1944 pilots of American bombers over the Reich encountered a number of small, swift craft of unusual design, which definitely were jet driven, but apparently had some other type of power than the thermal jet engines being developed in England and America.

They appeared, in fact, simply to be gliders equipped with jet motors that could be turned on when power was needed. Some pilots reported that the ship was able to complete vertical dives which were the fastest controlled flights ever made by man; up to 800 miles an hour.

The plane was described as having a short, stubby fuselage only two-thirds as long as it was broad, equipped with short, tapering wings, sweeping backward. The tail was thick and

stubby, equipped with a large fin but apparently no tailplane. The craft carried one man, under a transparent canopy at the front, and emitted puffy trails of vapor when under full power.

This new craft, officially called the Messerschmitt-163, was quickly nicknamed the "flying wing" and the "jetty." Reportedly they "swished past heavy bombers so fast the crewmen did not realize what they were." Fighter pilots were able to identify them more than a dozen miles away by the spectacular dense plume of white smoke stretching out half a mile or so behind each craft.

The reaction motors of the Me-163 may be of the continuous duct engine type, but it seems more likely they are liquid-fuel motors. Lieutenant Colonel John Murphy, a Mustang squadron commander who dived on one of the strange craft and shot it down after a vertical chase of 10,000 feet, reported afterward that he could smell "the chemical fumes" it was emitting. Such smellable chemical fumes suggest a motor using hydrogen peroxide or nitric acid as the oxidizer. Liquid-oxygen motors have no odor. It is also possible, of course, that solid fuels were being used.

Later observations of the still mysterious Me-163 indicate that its function was to serve as a high-altitude interceptor, and that its armament consisted of three rocket tubes in each wing and a cannon in the nose. It was believed to carry about ten tons of fuel at the takeoff, and to have a total burning time of eight minutes. The flying time, however, might total three hours, which the pilot managed by using his fuel advantageously to reach great altitude, at which point the motor was shut off and the plane handled like a glider. When too much altitude had been lost, the pilot could switch his motor on and again soar to the desired level. When opportunity for combat was presented, the pilot had usually three or four minutes of fuel left in his tanks, with which he was able to "fly like a bat," so fast Allied pilots were sometimes unable to determine whether the Me-163 was friend or enemy until the attack had begun.

7.

Continuing their gallery of new weapons which foreshadow the wars of the future, the Nazis in November, 1944, introduced

still another of their "Vengeance" weapons. This one, known as "V-2," was first shot against London, after months of preparation and advance propaganda.

The "V-2" turned out, as expected, to be a huge long-distance liquid-fuel rocket. Its destructive effect was by no means as great as the scare stories released through neutral sources had indicated, but otherwise the propaganda had been remarkably accurate.

In the autumn of 1943, for example, it was reported from Zurich that the Germans were conducting tests with a rocket bomb 45 feet long, weighing 12 tons, and intended for use in bombarding England. Thirty feet of the rocket's length was declared to be required for the fuel tank, and the reputed maximum range of the shell was 160 miles. The Zurich report stated that the Germans had actually shot these projectiles 35 to 40 miles in tests, and had "begun the assembly of rocket catapults on the French Channel coast."

This weapon was either the same or a close relative of the one reported early in January, 1944, from Stockholm. This rocket bomb, after being launched from an airplane, was said to climb to a height of 35 miles, travel 65 miles and then crash on its target, spreading "devastation over a radius of 1,300 feet."

"The bomb consists of three compartments and stabilizing wings," said the account. "One compartment contains a charge of 880 pounds of liquid air and uranium salt solution, the second holds the 450 to 650 pound propulsion charge, and the third contains the ignition mechanism believed to consist of radioactive salt solution and quicksilver."

What was evidently this same rocket was described some days later in a newspaper dispatch from Berne, Switzerland, in the New York *Times*. This story stated that the weapon was "nearing completion" in the region of Markdorf, near Lake Constance. The propelling charge was described as "C_2O_2[5] and picric acid," and the rocket was said to have covered distances of 110 kilometers (68 miles) with "reasonable accuracy."

The eyewitness quoted in this story saw an even more devastating effect than his colleague of the Stockholm paper. For the Berne men noted a clearing produced by one of the explosions in the forest which was 600 *yards* in diameter, "in which not a

[5] Possibly H_2O_2, or hydrogen peroxide.

vestige of trees or undergrowth remained. It was as though the bushes had been vaporized under the force of the explosion . . . while trees and bushes another 300 to 400 yards outside the ring of complete destruction were splintered."

The "V-2" rockets which finally began landing on England carried about a ton of high explosive; their length was between 40 and 50 feet, their greatest diameter was five feet. They were powered by a single regenerative liquid-fuel motor burning liquid oxygen and alcohol. The motor, according to the best information so far available, had a throat diameter of about 18 inches, a hemispherical blast chamber some four feet in diameter, and a total thrust at starting of 50,000 pounds, or somewhat less than 25 tons. The starting weight of the rocket was 12 tons, and about two-thirds of the starting weight consisted of propellants.

In design and construction, the "V-2" was very similar to many of the simple experimental sounding rockets projected in this country before the war—though of course vastly larger. The general shape was that of an elongated torpedo, with a sharp, conical nose, a cylindrical body, and a slight taper at the tail, narrowing down to the diameter of the outside diameter of the nozzle, about four feet. The flight was stabilized by four large fixed fins, and steering was managed during powered flight by small gyro-controlled carbon vanes set in the blast of the jet.

The warhead and detonator occupied the tip of the nose. Immediately behind the explosives compartment were located a radio-control device for cutting off the fuel at the proper velocity and altitude to control the range. In the same compartment was the stabilizing gyroscope and its auxiliary mechanisms. The main body of the rocket was taken up by huge cylindrical tandem fuel tanks, the alcohol tank placed ahead of the liquid oxygen tank. The alcohol fuel line passed through the oxygen tank, and both containers were so placed that the center of gravity did not change as the liquids were consumed.

Separate rotary pumps, driven by a single turbine wheel operated by superheated steam, were provided for each liquid. The steam supply—virtually the only unexpected item in the entire projectile, was obtained by reacting liquid hydrogen peroxide with calcium permanganate. These chemicals, carried in separate small pressure tanks in the turbine compartment at the rear, were permitted to come together as the first step in starting the rocket

on its flight. The result—steam at high temperature and pressure—passed through the turbine, starting the pumps working at a furious rate.

The alcohol was forced through a distributor from which extended six equally spaced tubes, leading the fuel evenly into the cooling jacket of the motor near the mouth of the nozzle. Spiraling upward around the throat of the nozzle and over the body of the blast chamber, the alcohol was then mixed with the incoming oxygen through a cluster of 18 injection nozzles at the top of the motor. Once ignited, the combustion of the propellants was continuous until all of the liquids were used up or the fuel cut off by the radio control apparatus.

The "V-2" rockets actually fired a little over 70 seconds, consuming in that short space of time nearly nine tons of alcohol and liquid oxygen and reaching approximately the speed of the jet—estimated at 6,000 feet per second. Such a rocket of course obeys well-defined laws of flight, and its course can readily be calculated. It must be shot at an angle of close to 85 degrees. Its starting acceleration will be something like 1 gravity. As the fuel is used up the acceleration rapidly increases, ending at about 5 gravity.

At the end of its first 36 seconds of firing the rocket will be four miles high, traveling at just under 1,500 feet per second. At the fifty-fifth second its altitude will be 10 miles, and its velocity approaching 2,900 feet per second. At the seventy-first second its altitude will be slightly more than 22 miles, and its speed greater than a mile a second.

By this time its trajectory angle will have fallen off to the favorable angle of 45 degrees; its fuel will be almost all consumed. If the power is then cut off it will continue to rise in its trajectory in free flight, reaching a maximum altitude of between 65 and 70 miles. The total earth-level distance of the flight will be a little over 200 miles. The total time of flight, from launching to landing, will be a trifle over six minutes.

This calculation checks closely with what the "V-2" was actually observed to do. These German rockets were not only the largest projectiles ever shot by man, but they reached the highest altitudes to which any artificial contrivances had previously been sent.

Despite the long period of preparation, however, the Nazis

did not succeed in solving the problem of directional control, with the result that the "V-2" rockets were quite erratic in flight. Some, presumably launched for London, actually landed in neutral Sweden. It seems probable that fewer than half reached England at all, while only a comparative handful struck London proper.

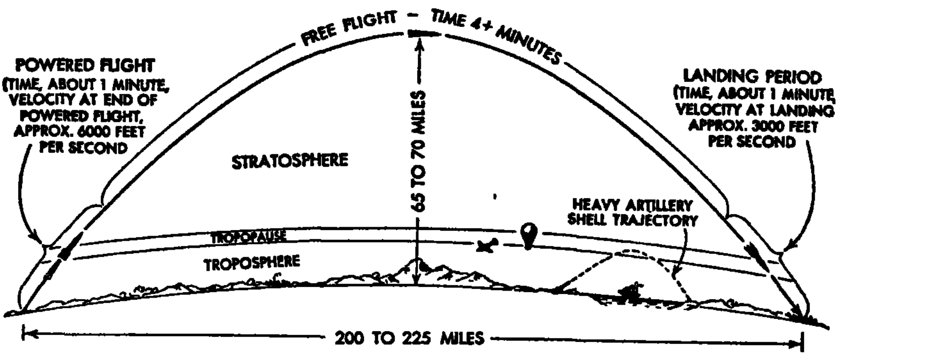


FIG. 20. Estimated trajectory of the German "V-2" rockets, compared with altitudes of earth's highest mountains, an artillery shell trajectory, and heights reached by balloons and aircraft.

There was, of course, no defense against those that made a true flight. The Allies are reported to have followed the course of every "V-2" by radar, from launching to landing, but were unable to do anything about either deflecting the course or shooting the projectiles down, once they had completed the powered part of the flight.

To Londoners, the "V-2" promptly became "the flying gas main" or "the flying telephone pole." In the daytime it gave absolutely no warning of its approach, since the velocity of descent was more than twice the speed of sound. Witnesses who saw the rockets at night described them as "falling stars" or "the tail of a comet"; they evidently glowed with the heat generated by rapid passage at perhaps better than 2,000 feet per second through the lower atmosphere.

The sound of the explosion upon landing often appeared double: two quick blasts in succession, and the noise could be heard farther than that of the robot bomb. The "V-2" usually blasted a hole about 30 feet deep and 30 or 40 feet across, but since its fall was nearly vertical, its destructiveness was not as great as that of the robot bomb, which came in almost hori-

zontally and usually struck high up on a building, spreading the power of its explosion over a wide area.

8.

Obviously, in World War II, the robot bomb, the rocket-powered glider and the long-range liquid-fuel bomb were not such weapons as could change the outcome of the contest. But in many ways these three were the most significant weapons developed in the war. They cast a long shadow into the future, affecting both the peace and wars to come.

The Allied nations—as not infrequently happens—at first scoffed but later themselves began experimenting with jet-driven robot bombs.[6] Whether they have also undertaken the development of other weapons, such as the "V-2," has not been disclosed, but it seems inevitable that nations will continue to develop them until the problem of accuracy has been solved.

Robert P. Patterson, Undersecretary of War, recently declared before a Congressional committee:

"An aggressor in the future will strike even faster than in the past, and with ten-fold fury. The weapons that are the actualities of today—rockets, jet-propelled bombs, guided missiles, to mention only a few—are incontrovertible evidence of this fact."

[6] The War Department disclosed on October 22, 1944, that it had contracted for the production of some 2,000 copies of the German robot bomb "for experimental purposes." Speculation was stirred as to whether the Allies might use buzz-bombs against the Japanese. Since then, considerable development and improvement of the weapon is known to have taken place in this country.

Chapter XII

Giant's Hand

I.

IN THE summer of 1944 persons living or working near installations of the U. S. Navy began to observe an interesting phenomenon. Whereas the Navy's flying boats previously had made laborious takeoff runs, with engines wide open and the sound reverberating across the water like artillery, they now began to zoom upward from the surface with virtually no run at all; seemingly shoved into the air by a giant's hand.

The giant's hand was a pair of reaction motors, one under each wing near the fuselage; the kind of reaction motors known as *thrustors.*

Thrustors used for assisting planes to take off are referred to as "jatos" for "jet-assisted takeoff." This particular service, of course, is the commonest to which thrustor units are put, and has economic and military value for a very simple reason: if an airplane can be given a suitable extra thrust at just the proper moment in the takeoff run, prolonged for just the proper amount of time, it will obtain one of several definite advantages: (1) the takeoff run may be substantially shortened, (2) the permissible payload may be increased, or (3) it may be able to operate with smaller, and therefore lighter engines.

In practice, jet-assisted takeoff is most frequently used to decrease the takeoff run. Since the run may thus be shortened as much as 50 per cent, big bombers can be launched from aircraft carriers, and interceptor planes can be cast into the air from smaller fields in much less time.

Like so many "new" things that have come out of the war, the idea of jet-assisted takeoff was proposed many years ago. As early as 1927 the German aviation magazine *Flugsport* published an article advocating the use of launching rockets, particularly

for pontoon-equipped seaplanes and flying boats, which sometimes have a difficult time breaking contact with the water.

In 1929 Hugo Junkers, founder of the German aircraft company that bears his name, carried out what were apparently the first full-scale experiments with jet-assisted takeoff, using a model J-33 Junkers seaplane of the same type as the "Bremen," in which Hermann Koehl, James Fitzmaurice and Baron Gunther von Huenfeld made the first westward flight across the Atlantic in 1928. The "Bremen" was a land ship; but Junkers put pontoons on the model he used in his experiments.

The tests were made near Dessau, Germany, and apparently proved successful. The takeoffs were assisted by a battery of large dry-fuel rockets made by the firm of Friedrich Wilhelm Sander, the same manufacturer who provided thrustors for the Valier-von Opel rocket cars and the Stamer and Opel gliders. Contemporary reports had it that the small Junkers plane was overloaded by about three tons for the test takeoff: an overload it could not have lifted without assistance.

In January, 1936, Dr. Eugen Sanger, of the University of Vienna, published the results of some studies he had made on assisted takeoff with liquid-fuel motors. Dr. Sanger was interested in ways to help pursuit and interceptor craft climb rapidly to fighting altitudes. Normally a pursuit ship weighing about two tons and capable of flight at top speeds of 320 miles an hour can climb from the ground to an altitude of 20,000 feet in about eight minutes. Dr. Sanger figured that with the aid of a liquid fuel thrustor the climb of 20,000 feet could be reduced to a minute and a half.

This was to be accomplished by installing in the plane three spherical tanks: for liquid oxygen, fuel oil and nitrogen pressure gas respectively. The motor was to burn 90 seconds, delivering one ton of thrust. Empty, the extra apparatus would weigh 205 pounds, Dr. Sanger calculated, and it would burn during the ascent 745 pounds of fuel.

Dr. Sanger confidently assumed that a liquid fuel motor capable of a ton thrust for 90 seconds could be built, and he presented in his report a schematic diagram of such a motor, with fuel-cooled walls and throat. To provide the expected thrust for 90 seconds on the calculated amount of fuel, a jet velocity of almost 8,000 feet per second would be required. Dr. Sanger

claimed he had actually produced jet velocities of 8,000 feet and more in laboratory models.

2.

So far in this country and England the principal practical application of jet-assisted takeoff has been the simpler one of getting heavy ships into the air with short runs or large payloads. Thrusts of 1,000 to 3,000 pounds for periods of less than a minute will usually serve this purpose. In most installations the empty apparatus is dropped at the end of the takeoff, so the weight of the empty jato will not add needless weight to the ship in flight.

Jato units are now regularly used by the Navy for both carrier-based airplanes and flying boats. The Navy jatos are large bomb-shaped cylinders filled with solid propellant. The fuel composition, the weight of the jato and the thrust have not been revealed, but the Navy has announced that each unit delivers sufficient power to provide the equivalent of 330 additional engine horsepower for the period of the takeoff.

Using these units, a navy fighter can cut its takeoff run in half, which means that carriers can utilize more of the deck space for planes; and can get more planes, and heavier ones, into the air more quickly. Jato-equipped navy planes can use little island airstrips safely, and thus can more quickly support forward troop movements.

The Navy's experiments with jato units began in 1941, at the U. S. Engineering Experiment Station at Annapolis, Maryland. A short time later the Guggenheim Aeronautical Laboratories at the California Institute of Technology were requested to build some small jet units for testing.

The first actual flight test took place on March 1, 1943. The pilot was Captain William L. Gore, of the U. S. Marine Corps, a jato enthusiast of long standing. Captain Gore, while still a private in the Marines, had carried on some jet-assisted takeoff experiments of his own, paying for the test motors out of his own pocket.

In the test flight, five jato units were installed on a small navy Wildcat fighter. Captain Gore taxied to the runway and then flicked the switches that electrically fired the units. There was a shrill, roaring noise like steam escaping from a high-pressure

boiler, and the Wildcat shot into the air on a column of white smoke. Bystanders gaped at the speed of the takeoff.

Just eighteen days later, the same plane was used to test the feasibility of jet-assisted takeoff from a carrier. This time the pilot was Commander Leroy C. Simpler, who had previously gained fame as the skipper of Fighting Squadron Five in the early days of the attack on Guadalcanal. This test also was successful.

These special jato units were produced by a new research and production organization, the Aerojet Engineering Corporation of Pasadena, California, which had been commissioned by the Navy in 1942 to work on jet takeoff apparatus. President of Aerojet is Andrew G. Haley, of Pasadena. Dr. Theodor von Kármán, director of the Daniel Guggenheim Graduate School of Aeronautics of the California Institute of Technology, was chairman until his recent resignation to undertake special work for the Army. The board of directors includes Dr. Frank J. Malina, of the California Institute of Technology, a well-known prewar rocket experimenter. Dr. Fritz Zwicky, the physicist, is director of research.

When the development job was turned over to Aerojet by the Navy, the units were promising but not powerful enough. By June, 1943, the Aerojet engineers, after less than a year of work, had succeeded in increasing the power five times. Orders were then placed for quantity production.[1]

Details of jet-assisted takeoff apparatus used by other branches of the armed forces and our Allies have not yet been disclosed, though the U. S. Army's Technical Air Service Command has recently been experimenting with jatos at Wright Field, Dayton, Ohio. Such equipment has by no means been confined to the Allied side. During the blitz of London in 1940 several large German craft shot down gave indications of having been jet assisted with dry-fuel thrustors. In other theaters in 1941 and later, captured load-carrying Junkers 88's and Heinkel 111's were found to be equipped with mounting devices for jet-assisted takeoff.

In these German planes a kind of curved grating was fastened to the underside of the fuselage, to which batteries of dry-fuel rocket motors could be attached in the quantity needed. These

[1] Considerable development of liquid-fuel jatos has also been done by Reaction Motors, Inc. (see page 42) since 1941.

were fired electrically by the pilot at the proper time in his takeoff run. Once in the air, a simple release mechanism dropped the grating and lightened the plane.

·3·

Manifestly the thrustor is the work-horse of the rocket tribe. Its day is only beginning. Organizations like Aerojet and Reaction Motors count heavily on further uses of thrustors, both in peace and war, to provide a continuing market for reaction motors. Many an engineer is producing plans and schemes these days to make use of the thrustor's unique combination of lightness and sudden enormous power.

The possibilities of Dr. Sanger's rapid-climb idea, for example, have hardly been explored, except perhaps in the Me-163. We may well see aircraft provided with a major portion of the power needed for the climb, simply by a small liquid-fuel or dry-fuel motor in the tail. G. Geoffrey Smith, editor of the British magazine *Flight*, has suggested the use of a thermal jet engine or the athodyd for this use also.

A tactical use of thrustors on fighting aircraft, either bombers or fighters, might be that of putting on a burst of unexpected speed in maneuvering for fighting position. The speed with which a conventional plane can move is well known by aviators, and while there are variations among the different types of craft, these are not so great as to throw off the quick calculations of an experienced pilot in battle.

However, if a pilot is expecting his quarry to move at say 300 miles an hour, and the quarry actually travels at 600 miles an hour for a short time, the effect may well change the outcome of the contest.

A jet-driven thrustor of the right type and power could readily make this possible. It will be surprising if such jet-assisted craft have not already been in the skies on one side or the other in the war, at least for experimental study. Jet-equipped planes would, of course, be primarily defense craft, since the extra weight of the jet motor and its fuel tanks would act to cut down the cruising range.

Bombers might also find extra speed in crucial moments sufficiently advantageous to justify a lighter bomb load in favor of an

auxiliary thrustor. In naval torpedo bombing, for example, the period of the torpedo plane's run, during which it is particularly vulnerable, could be materially shortened by a suitable thrustor. The getaway after the torpedo has been launched could be transformed into a flash over the hostile ship and away. In providing flying defense against the robot bombs over London in June and July of 1944, the British found it extremely difficult to catch up with the winged missiles with ordinary fighter craft. In most cases, the RAF could only dive on the robots, hoping to make a hit as they went by. Jet assistance in the air under such circumstances would make it possible for an airplane to keep up with—and overtake—fast-flying pilotless devices and put them out of commission at leisure.

Not the least interesting of the suggested applications of jet thrustors is their possible use as "air brakes" for big aircraft required to land on small space, such as a clearing in a jungle, or the deck of a ship. Thrustors so arranged as to fire in the direction of the flight could slow up an airplane very rapidly, by a reversal of the principle of assisted takeoff.

Braking by this method would require, of course, that propellants for the jet motors be carried from the beginning of the flight. One or more jet motors would have to be mounted in the plane, probably along the leading edge of the wing near the fuselage, with nozzles pointed straight ahead. In large craft, the relative weight of this special equipment would not need to be great. If the fuel were gasoline, only the oxidizer need be brought along as an extra.

4.

Another possible application of the thrustor might be that of providing gliders with a bit of short-term maneuverability of their own, including takeoff after having once been landed. During the war this was often suggested as a means of making greater use of glider-borne troops and equipment. Whether the scheme was ever tried under tactical conditions has not been disclosed.

In the invasion of Normandy, gliders filled with troops occasionally landed in what appeared to be open fields, only to discover too late that they had fallen into a trap. German machine guns and mortars were waiting for them on all sides, sheltered by hedges surrounding the invitingly empty fields. When the

gliders landed, they were promptly put under fire. In many cases they were unable to disembark their equipment or make a move to protect themselves.

Such gliders equipped with simple rocket motors and a suitable supply of propellant might have taken off again upon discovering the ambush, either to land in a better field or flank the enemy trap. Also, a source of lightweight, short-term power could make the military glider a returnable weapon, increase its usefulness as a transport and ammunition carrier, and enhance the effectiveness of airborne troops.

The possibilities of thrustor motors as auxiliary or primary power for high-speed boats have been under discussion for some years. As in auxiliary uses for aircraft, the idea would be to take advantage of the rocket motor's great power, lightness, low cost and compactness, where these qualities are more important than fuel economy or long-sustained performance.

It has been suggested that landing barges with special keels, permitting them to make high speeds, could well be powered with rocket motors. Another type of military vessel, the fast PT boats and their counterparts, could be given short bursts of phenomenal speed by auxiliary rocket motors.

Entirely new types of craft might well be developed to skim the surface of the water—almost flying—by rocket power. In time of war, they could deliver a torpedo into an enemy craft and escape almost before the defense weapons of the attacked ship could be brought to bear. Or they could be launched from shore or special carriers in such numbers (because of their cheapness) that the ship under attack could not hope to escape being hit by one or more of them.

In peacetime, fast rocket-driven boats of this sort could be used for carrying mail from ship to shore, for rescue work, for sports events. They might even open up a new field for watercraft, providing speed approaching that of the airplane.

Among the interesting experiments with such rocket-driven watercraft were those made in February and March of 1944 by the engineers of Reaction Motors. With Mr. H. F. Pierce as pilot, a number of experimental runs were made on the Severn River, near Annapolis, Maryland, with specially designed boats powered by a standard Reaction Motors 250-pound regenerative motor, fueled with liquid oxygen and gasoline.

Mr. Pierce found it no problem to reach speeds up to 40 miles an hour, but control of the boat became progressively more difficult as the velocity increased. No simple method of steering, as by rudder, seemed practical when full motor power was on, and he concluded that steering at high speeds would have to be accomplished by mechanically changing the direction of the jet.

Devices like the intermittent duct engine and the athodyd could also be used effectively to drive boats at high speeds. It would not be surprising if sports boats and special purpose utility boats of various sorts were to undergo radical redesign in the near future, to make use of the high velocities, light weight, cheapness and other advantages offered by thrustors.

Chapter XIII

To Scale the Heights

1.

THE ocean of air at the bottom of which we have our existence is one of the greatest unexplored areas of the earth. It is far bigger than the deeps of the sea; more mysterious than the dry unmapped deserts of Asia; more important in its effect on us, known and unknown, than the polar and mountain regions our geographers have so painstakingly plodded through in our generation. The air, above a few utilitarian miles, is an unknown region. It is forbidden to us except through rocket power. The rocket alone can operate in the state of comparative airlessness necessary to explore it. As Dr. Goddard wrote in *1919:*[1]

> The greatest altitude at which soundings of the atmosphere have been made by balloons, namely, about 20 miles, is but a small fraction of the height to which the atmosphere is supposed to extend.
>
> In fact, the most interesting, and in some ways most important, part of the atmosphere lies in this unexplored region; a means of exploring which has, up to the present, not seriously been suggested.
>
> A few of the more important matters to be investigated in this region are the following: the density, chemical constitution, and temperature of the atmosphere, as well as the height to which it extends. Other problems are the nature of the aurora, and (with apparatus held by gyroscopes in a fixed direction in space) the nature of the *alpha*, *beta* and *gamma* radioactive rays from matter in the sun as well as the ultraviolet spectrum of this body. . . .

He might also have added, were he writing it today: the cosmic rays, which lance in upon the earth's atmosphere from all directions in space and originate no one understands where; the

[1] "A Method of Reaching Extreme Altitudes."

Four years later, on May 27, 1931, Auguste Piccard and Charles Kipfer, Swiss scientists, rose 52,462 feet (nearly 10 miles) in an airtight, globular gondola made of aluminum, carried aloft by a huge pear-shaped hydrogen-filled balloon. They took off from Augsburg, Germany, and descended safely eighteen hours later on the Gurgl Glacier, in the Austrian Tyrol. Subsequently Piccard, accompanied by Max Cosyns, a young Belgian scientist, beat his own record, reaching an altitude of somewhat more than ten miles.

In this country a number of ascents and attempts at ascents were made following the great interest aroused by Piccard's successes. To an American team of balloonists finally went the honor of having ascended to the highest elevation reached by man. This flight, sponsored jointly by the National Geographic Society and the U. S. Army Air Corps, took place on November 11, 1935, beginning from the Black Hills in South Dakota, and ending on a farm on the broad flatlands of southeastern Nebraska. The balloonists who made the flight were Captain Albert W. Stevens, U. S. Army, and Captain Orvil A. Anderson, U. S. Army. The altitude they reached was 72,395 feet (nearly fourteen miles).

That manned balloons will ever go much higher is doubtful. The flights are so intricate and difficult the data obtained are hardly worth it, particularly when there are safer and less costly ways of getting it.

One of the most successful of these is the free sounding balloon, now used by weather men both for routine observations and meteorological research. Sounding balloons with recording instruments have reached altitudes of nearly twenty-two miles. Small pilot balloons without instruments, but observed from the ground by means of telescopes and theodolites, have gone a mile or two higher. The free balloon record is twenty-four miles.

3.

What is known about the air above twenty-four miles depends on calculations and estimates; on the sort of scientific detective work that takes its clues from observations of the behavior of meteors, auroras, light refraction and radio waves. A great deal has been learned, deduced and suspected by these methods, but

what is needed is a real sounding device that can physically reach the heights, measure their phenomena directly, and if possible bring some samples back.

The rocket, of course, provides a possible means of reaching these altitudes. It can penetrate the rarefied upper atmosphere because it carries along its own oxygen supply. It can exert thrust even where there is no air, because it does not need anything to push against. It can travel swiftly, in a predetermined direction, and come back with its information while the data are still news.

Against these advantages we must weigh the rocket's deficiencies. It necessarily burns up a large portion of its mass in making the ascent; hence must start with a heavy load of fuel, leaving relatively little carrying power for the payload of instruments. It needs to be directed in flight, even when the flight is vertical, and the equipment for doing this is not yet well developed or reliable. Finally, many of the instruments which the rocket is to carry must be especially developed for this use. Those now employed for sounding balloons may be too fragile —and speak too slowly—to record the conditions of the atmosphere during a rocket ascent.

Several years ago, in a communication to the American Rocket Society, C. G. Clark of the United States Weather Bureau pointed out that the altitudes required of a meteorological rocket would naturally depend on the phenomena to be explored.

> For example [wrote Mr. Clark], if the rockets are intended to replace airplane weather observations, the minimum altitude required would be set at five kilometers (about 16,500 feet). If the rockets are intended to reach the stratosphere in these latitudes (Washington), the minimum altitude required would be usually from about 12 to 18 kilometers (7 to 11 miles).
>
> If the object of the rocket investigations was to reach the zone from about 40 to 50 kilometers, where explosion observations (of meteors) indicate sound velocities of high value and refraction . . . the minimum elevation just specified (25 to 30 miles) might form a desirable minimum. If it be desired to reach the level of maximum frequency of occurrence of auroras, elevations beyond 85 or possibly 120 kilometers (53 to 75 miles) would be necessary.

We are thus presented with an ascending scale of required rocket altitudes:

For routine weather observations, 3 to 5 miles
For sub-stratosphere explorations, 7 to 11 miles
For soundings in the lower stratosphere, 15 to 20 miles
For soundings in the meteor explosion belt, 25 to 30 miles
For exploration of the aurora zones, 50 to 75 miles

With the liquid-fuel motors now available as a result of wartime research, all of these altitudes apparently are within reach, though suitable rockets are still to be developed.

So far as power is concerned, a motor delivering a jet velocity of 6,000 feet per second and capable of a steady thrust of 3,000 pounds should be able to drive a suitably designed rocket to an altitude of at least 60 miles. Such a motor would consume 16 pounds of fuel each second of firing. If the firing time were to continue one minute, accordingly, a fuel load of 960 pounds would be required. If the rest of the rocket, including the sounding instruments, could be constructed to weigh 540 pounds or thereabouts, the starting weight would be about 1,500 pounds.

Disregarding the resistance of the air for a moment, the velocity of such a rocket would be 5,318 feet a second at the end of its powered flight, and it would already have risen more than 160,000 feet. It would then continue in free flight for 181 seconds, reaching a total altitude of nearly 642,000 feet, or 122 miles.

Unfortunately, however, the resistance of the air cannot be disregarded in a real problem, and at these velocities it would be high. The amount by which air resistance would reduce the altitude cannot be accurately calculated for a general case, since it depends on the cross-section of the rocket, the speed, the shape of the rocket, the altitude of the launching, the altitude reached at the end of the powered flight, the starting and final masses of the rocket, and other variables, including temperature, barometric pressure and the amount of moisture in the air. It is probable that for the type of rocket we are considering, it would be such as to reduce the theoretical airless altitude by as much as one-half. Thus, though our sounding rocket might have gone 122 miles high if the earth were an airless globe, it may actually reach an altitude of only about 65 miles, if launched from sea level.

The same type of rocket would be able to add another 10 to

15 miles to its altitude in the air, if the weight of the empty rocket and payload could be kept down to 500 pounds, allowing for a fuel load at starting of 1,000 pounds. Such a rocket would have an average acceleration of 3g, would fire for nearly 63 seconds, and would reach a total probable altitude in the air of 75 to 80 miles.

These calculations are based on a motor that can deliver 6,000 feet per second jet velocity. An improvement in the motor, to yield 7,000 feet per second jet velocity, would make a considerable difference in the altitudes that could be reached. With such a motor it should be readily possible to send a sounding rocket 100 to 150 miles high.

4.

From these estimates of the availability of the power, a solution to the problem of sounding rockets seems within grasp. It remains, however, for the engineers and designers to develop a suitable rocket for the job.

One interesting proposal is that outlined by Willy Ley in his recent book, *Rockets, the Future of Travel Beyond the Stratosphere.*[2] Ley's sounding rocket is based on the design of the VfR one-stick Repulsors. Two narrow cylindrical tanks are joined end to end and supplied with suitable valves and tubing to convey the fuels (liquid oxygen and alcohol or gasoline) to the motor, which is mounted forward in a fragile cage formed by the fuel lines. The motor is water or fuel-cooled, and resembles the Repulsor motors.

The instrument compartment and the parachute boot are located behind, amid four fixed metal guide fins. In his design Ley provides no other guiding mechanism, relying entirely on the aim and stability of the rocket to keep it on its vertical course. He does, however, suggest that a gyro-control might be necessary, and concludes that a suitable one could readily be constructed, to operate movable flaps on the vanes.

To reach an altitude of about 85,300 feet (about 16 miles) he calculates that a rocket of this design will be about 4 inches in diameter; will have tanks something over 100 inches long. The starting weight will be 44 pounds, the motor thrust 132 pounds,

[2] Published by the Viking Press, New York, 1944.

giving a starting acceleration of 2*g*. The fuel load appears to be based on the assumption that the motor will be able to deliver a jet velocity of 2,500 meters—about 8,200 feet—per second. Since this has been accomplished only under very special laboratory conditions, and is considerably greater than is likely in field operation for small motors of the sort described, Ley's expected altitude perhaps would not be realized with this design.

Of considerable promise is the design for a meteorological rocket proposed by James H. Wyld in 1939, and described in *Astronautics* for February of that year. Mr. Wyld presents a compact torpedo-shaped rocket of the modern type, with the motor at the rear and an instrument compartment in the nose.

As designed, it would be 9 feet long and 5 inches in diameter, cylindrical in cross-section, "with a long ogival nose, a conical tail fairing and four elliptical tail fins with movable rudders."

As described in *Astronautics* the proposed rocket would weigh about 17 pounds empty and would carry 18 pounds of propellant, consisting of 11.25 pounds of liquid oxygen and 6.75 pounds of ethyl alcohol. Wrote Mr. Wyld:

> The fuel tanks are tandem, and are built up of light 0.25 inch sheet metal, silver-soldered at the seams. They are of nearly equal size, and are filled slightly more than half full. The upper tank, of Monel, contains the loxygen; this is fed through a central tube in the alcohol tank; the latter is chrome-moly steel. The loxygen tank has a safety disc which ruptures under excessive pressure, and also a vent valve, which is closed immediately before firing. Nitrogen pressure is introduced into both tanks through fittings on the launching rack, until 250 pounds per square inch is reached, and the rocket is then fired at once.

In similar detail, Mr. Wyld presents the other features of his rocket. It is to have a gyro-stabilizer consisting of a single four-inch gyro suspended at its center of gravity on a small gimbals attached to the bottom of the parachute boot. The gyro, by means of an air blast, is to be brought up to speed of 10,000 revolutions per minute just before firing. The gyro is to be connected to gas-operated pistons placed in such a way as to control the movable rudders on the guide-fins, the operating pressure to be supplied from the nitrogen in the alcohol tank. The gyro is also to release the parachute at the proper moment,

by electrically igniting the powder charge in a "paragun," ejecting the parachute sidewise out of its compartment near the tail of the rocket.

Very conservatively calculated, from all known data of motor performance and air resistance, Mr. Wyld concludes that a rocket of this size would reach an altitude of three to five miles, with instruments. It would serve as an experimental rocket, to gain experience for the construction of larger ones capable of very much greater altitudes.

To date, neither the rocket suggested by Mr. Ley nor that of Mr. Wyld has been constructed. Ley believes it would be possible to develop a practical rocket along the lines he has set forth, provided funds were available for the work. His calculation is that $2,000 to $3,000 per month would be needed (exclusive of overhead) for a period of "not less than two but not more than three years."

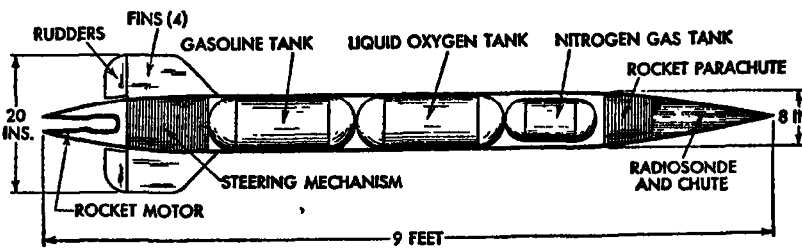


FIG. 21. General plan of high altitude sounding rocket designed by engineers of Reaction Motors, Inc.

Without special financing, Mr. Wyld began the construction of his proposed rocket in 1939, and had completed a suitable gyro-mechanism and developed his regenerative motor—originally designed for this rocket—before the war plunged him into liquid-fuel rocket developments of a more immediate and pressing sort, as design engineer for Reaction Motors, Inc.

Reaction Motors has since developed the design still further, as a possible postwar project. The proposed RMI sounding rocket employs a regenerative motor of 250 pounds thrust. The rocket, empty, will weigh 43 pounds, including a two and a half pound radiosonde. The loaded weight will be 110 pounds, thus providing for 67 pounds of fuel.

The calculated altitude, with full allowance for air resistance, is six to ten miles, enough to reach the stratosphere. The design

is inherently capable of much greater altitudes in larger sizes, and it should be possible to send instruments by such a rocket about 90 miles, or well above the aurora zone of Mr. Clark's projected series. The calculations for this rocket are based on Reaction-Motors' standard liquid-fuel motor design, producing jet velocities, with liquid oxygen and gasoline, of somewhat more than 6,000 feet per second.

To go still higher, for soundings into actual space, there are several possibilities. A successful liquid-fuel step-rocket has not so far been developed, but there should be no reason why one could not be forthcoming. The liquid-fuel step-rocket presents some formidable mechanical problems, but all of them are no doubt capable of solution.

As a sort of intermediate step, it might be feasible to develop a combination of liquid- and dry-fuel rocket, the dry-fuel portion to serve as the second step. It could be contained in a compartment at the tip of the liquid-fuel rocket, and would itself carry the instruments and their parachute.

Discounting liberally for the unknowns in such an untried proposition, we might confidently expect that altitudes of between 100 and 150 miles could readily be reached in this way. Such a combination does not appear to present any insuperable problems.

With a two-step *liquid-fuel* rocket, at jet velocities of between 6,000 and 7,000 feet per second, it should be possible to shoot instruments of small size and light weight as high as 200 miles. Altitudes beyond that will have to await the development of three step-rockets (which would be complex indeed!) or better motors.

With every increase in jet velocity, reachable altitudes climb in proportion and greater jet velocities are certainly to be expected. The ultimate in attainable altitudes is therefore not yet in sight.

5.

The design and construction of instruments for sounding rockets may turn out to be a real challenge to engineers too.

In very high shots, one of the major problems may be simply that of determining how high the rocket has gone. As long as the altitudes are limited to regions below the stratosphere, a

recording aneroid barometer might do this job. But as altitudes increase, the air becomes so rarefied ordinary barometric readings will contain an impossibly large margin of error.

Some years ago Dr. William J. Humphreys, of the U. S. Weather Bureau, suggested that high-altitude determinations might be accomplished in three ways: (1) in the daytime, by trigonometric measurements of smoke clouds, produced at definite intervals by chemicals placed in the fuels of rockets, or otherwise ejected from them; (2) at night, by flashes of magnesium instead of smoke clouds; and (3) by the measurement of vacua in a series of exhausted vessels arranged to be opened and resealed at predetermined altitudes.

To these might now be added: by triangulation of the rocket from three or more short-wave receiving stations, tuned to a continuous radio signal emitted by the rocket, or simply by following the rocket with radar. These schemes would work at night or in cloudy weather as well as in the daytime, and would permit accurate measurement even to very great altitudes.

A simple, compact and sturdy instrument to measure temperature and pressure, especially for use in weather rockets, was proposed by Dr. S. P. Fergusson, of the Blue Hill Observatory, Hyde Park, Massachusetts, in the *Monthly Weather Review* as long ago as June, 1929. The suggestion was stimulated by the promise of Goddard's early work, and Dr. Fergusson's design takes account of the necessity for ruggedness and lightness of instruments intended to ascend by rocket power—particularly those powered by dry fuels.

The apparatus consists primarily of two helical Bourdon tubes[3] secured to a light, stiff metal frame so that their free ends move in opposite directions when there is a change of pressure. One Bourdon tube in Dr. Fergusson's instrument carries a small record plate, and the other a temperature element.

The temperature element consists of two or more strips of very thin bronze, connected by spring hinges and mounted in a light invar frame in such a manner that changes of length, corresponding to changes of temperature, are engraved on the record plate by a stylus. A very small instrument can thus be

[3] Curved Bourdon tubes are flexible and hence tend to straighten when the gas pressure inside them exceeds that of the surrounding medium. The amount of movement is proportional to the pressure.

made to record temperature and pressure (from which altitude may be determined up to about 50,000 feet). The whole instrument should weigh only about two or three ounces.

For rockets able to carry a larger load, instruments now available can relay to stations on the ground an instantaneous record of their data while in flight, by means of a small short-wave radio transmitter.

Manufacturers have done some amazing things with instruments of this type. The Friez Radiosonde, made by the Friez Instrument Division of the Bendix Aviation Corporation, at Baltimore, weighs only 1½ pounds, and is contained in a small box 8 inches wide and 4 inches deep. It measures barometric pressure, humidity and temperature over a wide range, and carries its own radio transmitter and battery. Humidity is measured over a range of 15 per cent to 100 per cent; temperature from 60 degrees above zero Centigrade to 90 degrees below. Its radio signals can be picked up at more than 100 miles.

These are of course basically weather instruments. When sounding rockets begin to reach into the stratosphere, other instruments will have to be designed for the special research they are to do. There will be need for light, compact and accurate ionization meters, ultraviolet meters, ozone samplers, spore counters, cosmic-ray meters, rare-gas samplers, and meteoric dust recorders. There may also be required tiny, lightweight high-precision cameras for astronomical photography at high altitudes, small spectrographs capable of bringing back analyses of solar and stellar radiation from the edges of the atmosphere, and perhaps diminutive wide-angle infrared cameras for use in taking large-area pictures of the earth, for use in surveying, exploration, searches for lost persons or aircraft, and the like.

James H. Wyld, who has given some study to this problem, foresees the development of an entirely new field of instrument work, which might be called "micro-instrumentation" by analogy with the science of micro-chemistry.

> There has seldom been an application hitherto for very tiny, light, special instruments, so they have not been developed [he wrote to me recently in a memorandum on rocket sounding instruments]. However, there is no reason at all why we cannot have, say, aneroid barometers no bigger than a dime and

> weighing two or three grams, and other instruments in proportion.
>
> The whole instrumentation of a sounding rocket might include, say, 100 different instruments, yet they would weigh perhaps five pounds in all—including radio equipment.
>
> It is not generally realized to what lengths this idea has already been pushed. There is one form of radiation-measuring instrument which consists of one or two house-fly wings mounted on a filament only a few per cent of a human hair in thickness. There are also vacuum thermopiles which have, among their most massive parts, a receiving screen of gold leaf 0.5μ (.00002 inch) thick, and three millimeters by three-tenths of a millimeter in area—the weight being about nine milligrams, or .00002 pound.

As Mr. Wyld goes on to relate, the necessary mounting of this latter instrument "fabulously increases" the weight, so the whole thing turns out to be about an inch long and weighs perhaps as much as a nickel!

Chapter XIV

Over Land and Over Sea

1.

SOME time between the early months of 1929 and the first week of December, 1930, a young Austrian inventor and rocket experimenter named Friedrich Schmeidl commenced an activity that has earned him a unique place in history. By firing six experimental rockets, followed by a public demonstration, he launched the first mail-rocket line on record. Schmeidl's rockets were thus more or less ancestral to all the payload-carrying trajectory rockets of the world.

Schmeidl's mail line was operated intermittently over a period of more than four years, officially beginning on March 2, 1931, when he publicly fired his "V-7" rocket, correctly announced as "the first rocket-post of the world." It carried 102 letters between the small towns of Schockel and Radegund, not far from Graz. The crow-flight distance between these two Austrian towns was only about two miles, but the distance by road was several times as far. Consequently the rocket post was a practical service and much appreciated.

By September, 1931, Schmeidl had succeeded in having his rocket-mail line recognized as part of the regular postal service of the Austrian government, and he continued to fly it at periods until 1934. His first rocket post "open for general posting and acknowledged by the postal administration at Graz" carried 333 letters. It was shot on September 9, 1931, between Hochtrotsch and Semriach, Austria. On this occasion he pasted on all covers a special rocket-mail stamp, which he announced as "the first rocket stamp of the world."

Continuing his "firsts," Schmeidl made the "first rocket-mail shots" between a series of Austrian towns in the vicinity, mainly as a means of stirring up interest. Late in 1933 he developed a

type of dry-fuel step-rocket. In the same year he developed a catapult device for launching it, increasing the range.

Schmeidl's rockets, though crude in appearance, were pretty remarkable in their way. All of the many shots, except the first experimental ones, took off and arrived safely. The parachute opened every time: no mail was lost in any of the shots. They were, of course, dry-fuel rockets: powered by a mixture of potassium nitrate, potassium chlorate, charcoal and sulphur, mixed and loaded according to a private formula which Schmeidl did not disclose.

The unloaded rockets weighed 15 pounds. The weight of the fuel was a little over 50 pounds. The body of the rocket was about five feet in length and nine inches in diameter. It was steered by three short, fixed metal fins. The rocket case was of aluminum and brass, and the mail was carried in a cone-shaped compartment at the nose. The range of these rockets was about two miles

2.

The success of Schmeidl's rocket mail—and it was not only an experimental success: it was also a small financial triumph—soon brought him several imitators. Stamp collectors in many countries sent mail to be posted by Schmeidl rocket; Schmeidl's stamps were fast sellers in the philatelist's market.

One of the first young Europeans inspired to open a competitive operation was Gerhard Zucker, who started his own mail-rocket line with a three-mile shot between Hassefelde and Stiege, in the Harz Mountains in Germany, in August, 1933. He later made other successful shots in Germany, and a year later he visited England to repeat the exploit. One of his English rockets, which confidently carried several pounds of mail including a letter addressed to the King, was intended to go from Harris to Scarp, in the Scottish Hebrides, but it blew up instead.

A series of such accidents, traceable to bad luck and poorly made rockets, finally caused Zucker to abandon the trials and return to Germany, where he is reported to have been arrested promptly by the Nazis, presumably for disclosing his "secrets" to the British.

In the United States there were some experiments along the same line. A shot announced as the "first international rocket air

mail flight" took place on July 2, 1936, the rocket mail being sent from McAllen, Texas, across the Rio Grande to the city of Reynosa, Mexico. The demonstration was sponsored by the American Legion, and officials of McAllen and Reynosa participated, the mayor of McAllen touching off one of the several rockets. Each rocket carried about 300 covers. After several had been shot from the American side, the official party went over to Mexico by bridge, and shot some Mexican mail into the United States in return.

Rockets capable of carrying such exhibition and stamp-collector mail for a few hundred or thousand feet are not difficult to produce, so it is not surprising that a great number of shots were made both here and abroad. In 1935, a Brooklyn, New York, philatelist, Mr. F. W. Kessler, was able to publish a specialized catalogue, apparently the first, of "rocket-air-mail stamps." Dedicated to Schmeidl as "the first man in the world to successfully fly mail by rockets," Mr. Kessler's catalogue listed and illustrated fifteen different Austrian rocket-mail stamps (all produced by Schmeidl), twenty or more German stamps; nine British stamps and six rocket-mail stamps originating in India, including one ship-to-shore stamp. The latter was dated September 30, 1934.

Mr. Kessler himself became interested in rocket-mail flights during a trip to Germany and Austria in 1934, and in 1935 organized an ambitious project for shooting rocket mail from New York to New Jersey across the middle of Greenwood Lake, which lies between the two states.

For this project, two large aluminum gliders of about fifteen-foot wingspread were constructed. Liquid-fuel rocket motors to drive them were developed after a series of ground tests in New York City and at the site of the proposed flights. The aerodynamic form of the gliders was worked out under the supervision of Dr. Alexander Klemin, of the Guggenheim School for Aeronautics at New York University. Associated with the development of the motors were H. F. Pierce, subsequently president of the American Rocket Society, Nathan Carver, a member of the society's experimental committee, and Willy Ley.

The motors burned alcohol and liquid oxygen, and were apparently the first liquid-fuel motors used in a rocket-mail project. So many unsolved problems had to be overcome in coupling a rocket motor to a glider that many delays were experienced.

The mail shots finally were made on February 2, 1935, across the ice on the lake. The motors showed themselves able to lift the 120-pound planes into the air and propel them upward at a steep angle of climb. But the short burning period of about 30 seconds, coupled with several mishaps, reduced the distance covered to about 1,000 feet.

3.

All of these preliminary and experimental shots were interesting—and in many ways valuable. But manifestly they proved little as against the main problem of long-distance trajectory mail and express.

Getting distance with rockets in trajectories is a problem closely related to getting distance in high-altitude shots. It is principally a matter of building up enough velocity during the firing period to permit the projectile to coast through the balance of its journey like a cannon shell.

Treating the rocket as a simple projectile, assuming a free flight angle of 45 degrees, and ignoring air resistance, the velocities required at the beginning of free flight would be, in round numbers:

FOR A TRAJECTORY OF	VELOCITY AT BEGINNING OF FREE FLIGHT
100 miles	4000 feet per second
150 "	4900 " " "
200 "	5800 " " "
300 "	6900 " " "
400 "	8000 " " "
500 "	9000 " " "
1000 "	12700 " " "
3000 "	22000 " " "

Thus if a speed of something like four-fifths of a mile a second can be achieved by a suitably designed rocket at the end of its firing period, it will be able to shoot about 100 miles. Or if it can reach a speed of somewhat less than a mile a second, it can travel 150 miles. If a velocity of about two miles a second can be achieved, the rocket will go 1,000 miles. A velocity of four and a half miles per second would enable it to cross the Atlantic.

These distances assume, of course, that the rocket will be aimed upward at the most suitable angle at the time of gaining the maximum velocity, and that the altitude by that time will be great enough so that resistance of the air will be negligible.

Now these are obviously by no means impossible velocities. Ignoring still the resistance of the air—and also the effect of gravity during the powered part of the flight—any rocket so constructed that it carries nearly twice as much fuel as its own dry weight—that is, a rocket that weighs about three times as much loaded as it does when empty, will attain the velocity of its own jet.[1] This follows from the principle of reaction and provides us with a handy rule of thumb for estimating the performance of a given rocket without going through the tedious calculations otherwise required. All we have to do is plan for a rocket with a 2 to 1 fuel-weight ratio, and we can then proceed on the assumption that it will reach approximately the speed of its jet by the end of its firing period.

Now, with motors of presently available types, we can confidently expect jet velocities of between 6,000 and 7,000 feet per second. Using such motors to power trajectory rockets, we should be able to shoot distances of between 200 and 300 miles, without any further motor development than at present. Not only does theory indicate it, but the German "V-2" rockets, with ranges of more than 200 miles, have proved that the theory can be reduced to practice.

To reach 400 miles with a 2 to 1 fuel-weight ratio rocket, however, will require the production of very much better motors than are now in sight, for the rocket will have to reach a velocity of 8,000 feet per second. There is another way to get at the problem, though, and that is to make the rocket go faster than its own jet. This can be accomplished by increasing the amount of fuel relative to the structural weight. With a 6,000 to 7,000 ft/sec motor, a fuel-weight ratio of about 3 to 1 should provide a final velocity of the rocket of 8,000 feet per second.

Of course, constructing a rocket with this fuel-weight ratio,

[1] The exact ratio is 1.71828 to 1; that is, 1.72 pounds of fuel for every pound of construction weight. This exact ratio is of theoretical value only, however, since it would hold true only in space, where neither air resistance nor gravitational attraction would affect the rate at which the rocket could gain speed.

while possible, would call for considerable ingenuity. A 3 to 1 rocket would have to carry 750 pounds of fuel out of every 1,000 pounds of starting weight, leaving only 250 pounds for the fuel tanks, controls, valves, landing equipment—and payload. The payload obviously would have to be small.

By increasing the fuel-weight ratio still more, a 500-mile rocket could be constructed, too. Pumps and other weight-saving devices would undoubtedly have to be applied to the rocket to lighten it. The payload would be very small indeed, for it would have to come out of the very slender margin of allowable structural weight. A 500-mile rocket, with a 6,000 to 7,000 ft/sec motor, would have to be constructed on a fuel-weight ratio of around 4 to 1: permitting only one pound of structure and payload for every 4 pounds of fuel.

4.

To shoot more than 500 miles, we have a choice of several methods. The best would be to find some way to increase the jet velocity of the motor, either by more powerful fuels or by operating at higher temperatures and pressures.

The next best device would be the old reliable of the theorists —and the bane of the engineers—a step-rocket. Such a multiple projectile, though a terrifically difficult object to construct properly, would provide velocity for trajectory shots in the same manner as for high-altitude flights. The first step, of course, would be lost along the way at each shot.

The combination liquid-fuel and dry-fuel step-rocket discussed on page 182 should be capable of developing a top velocity of better than 7,300 feet per second, and accordingly should fly close to 350 miles. By making the second step a liquid-fuel rocket, with a jet speed of 7,000 feet per second and a fuel-weight ratio of 2 to 1, it should be possible to shoot the smaller projectile at least 1,000 miles, though the payload, if the starting weight were only 1,500 pounds would be only a pound or two.

Another possibility worth considering is the catapult or rocket booster—a jet-assisted takeoff apparatus for the load-rocket. A suitable catapult would require permanent launching emplacements of very large size. The takeoff run would have to be fairly long to spare the rocket the dangers of excessive acceleration,

and give room to develop high launching speed. The side of a steep mountain would be the likeliest location.

If the catapult could be safely operated at an acceleration of 5g, or 160 feet per second per second, and the track were a mile long, 8 seconds would be required for the car to go from one end to the other and eject the rocket. At the upper end the velocity would be 1,280 feet per second.

The rocket, of course, would start where the launcher left off, adding its velocity to the speed already received, less the amount substracted by gravity and the resistance of the air. If the rocket were capable of reaching a velocity of 6,000 feet per second without a launcher, it would make something better than 7,000 feet with the help of the catapult. This would increase its range by about 100 miles.

If the catapult were two miles long instead of one, the launching run would start the rocket on its way with a speed of 1,760 feet per second—enough extra boost to make a 300-mile rocket into a 450-mile one.

Even greater launching speeds could be attained, of course, depending on the rate of acceleration, the length of the run and other factors. There is a point, however, at which greater launching speed will fail to result in a gain in distance. A one-mile catapult, at 5g, would launch the rocket at rather better than the speed of sound. The wind resistance at this launching velocity might be so great as to defeat the purpose of the launcher, and faster launchings might actually work to the disadvantage of the rocket.

5.

Leaving these problems to the engineers, it is interesting to speculate on what practical results could be accomplished with load-rockets even if we must be content with trajectories of 500 miles or less.

The distance between many of the large cities of Europe is less than 500 miles. From Paris to London, for example, is only 213 miles; from Warsaw to Berlin, 325 miles.

In the United States, there is heavy traffic in mail and express between such cities as New York and Washington (228 miles), New York and Pittsburgh (369 miles), Chicago and Cincinnati (294 miles), Chicago and Detroit (272 miles) and Chicago and

St. Louis (294 miles); or from San Francisco to Los Angeles (404 miles), from Denver to Santa Fe (410 miles) or from Omaha to Minneapolis (367 miles). Rocket-mail lines capable of shooting up to 500 miles could link all of these cities.

Cities that have no direct connection by rail, and must depend on the slower transportation of mail by boat, should be especially interested in rocket lines. Across the Mediterranean from Rome to Tunis is only 375 miles. A rocket could cover it in about seven minutes. The distance from Toronto to Cleveland, across Lake Erie, is about 200 miles: a rocket could shoot from one to the other in six minutes. From Toronto to Milwaukee, a long awkward distance across parts of Lake Huron and Lake Michigan, is about 500 miles by air. It could be covered in less than eight minutes.

In South America rocket mail and express should find a tremendous welcome. Instead of requiring large and expensive equipment such as airplanes to carry the mail over the Andes and through the jungle, trajectory rockets could do it, without pilots or airports, in a fraction of the time.

So swift would be this rocket mail and express service, so free from the vagaries of wind, weather, night, day or the seasons, that it is not difficult to imagine rocket-mail networks linking not only the principal cities of the earth, but also spanning the deserts, rising over the mountains and crossing the oceans.

Even if the ultimate practical limitation should turn out to be 500 miles—which is hard to accept—this would be no real barrier to the covering of tremendous distances by rocket mail. Landing and launching stations could be established along a route all across the Sahara, for example, linking Cairo with the west coast of Africa. This mail and express service would require only two hours to travel the 3,600 miles from Cairo to Dakar, and of this time, more than half would be used up at the six or seven interlinking stops. The actual flying time would be only about 56 minutes.

For cross-ocean hopping, island to island relay systems could link Australia to Singapore or the Asiatic mainland by establishing rocket ports along the MacArthur route from Cape York Peninsula to New Guinea to Halmahera to Mindanao to Luzon to Formosa to Shanghai. With only slightly longer range rockets, the north Atlantic could be spanned from France to the United

States via England, the Faroe Islands, Iceland, Greenland, northern Labrador and Canada.

Rockets of 1,000 miles range would, of course, greatly increase the speed of transmission over long distances; would potentially bring into the rocket-mail net many more centers of population. Rockets with ranges up to 3,000 miles would permit transatlantic mail and express direct from England or the Continent and would open up rocket-mail routes from western Africa to South America.

6.

It is already possible to make some reasonably good guesses about the appearance, size and other characteristics of these fast load-carrying rockets of the future.

As to their appearance, they will be comparatively small in cross-section, sharply pointed to puncture the lower layers of the atmosphere through which they will have to pass with furious speed. Their bodies, consequently, will be long and slender—more nearly resembling huge darning needles than the fat rockets of scientific-fiction tradition. They may have small fins or vanes for steering, but this more likely will be accomplished by swiveling the nozzles of the jet motors, or by vanes directly in the blast of the jets. In the upper levels of the atmosphere, and especially at supersonic speeds, ordinary vanes, ailerons, flaps and the like will be useless.

These rockets will of course not be piloted, except by automatic devices pre-set to the course. There will be no need to provide any space of equipment for human passengers. Mail rockets will be strictly utilitarian devices built for a specific purpose and carrying nothing which is not needed for the accurate accomplishment of that end.

The motor, or motors, will probably be located behind. Just ahead will be the robot pilot and servo-mechanisms which will work the apparatus needed to hold the rocket on course. Still further ahead will be fuel and oxygen tanks, pumps for handling the propellants, the valves and controls. The fuel tanks will be so arranged as to maintain a constant center of gravity in the rocket as the propellants are used up.

The payload compartment very likely will be just forward of the fuel tanks. The nose of the rocket may contain instruments

for recording the conditions of the flight or equipment for emitting radio signals announcing the projectile's whereabouts. The rocket may also carry radio apparatus for providing some degree of remote control.

The flight of such a projectile will be typical of all rockets in trajectory. It will begin with an ascent at a steep angle, calculated to provide a flight angle of 45 degrees at the end of the powered flight. The rocket will move at an accelerated rate until its fuel is all used up. By this time it will be rising toward the highest part of its trajectory, will be traveling at a velocity of the order of a mile to two miles a second (depending on the distance to be covered) and will be 50 to 100 miles above the surface of the earth. The powered part of the flight may require a minute to a minute and a half; for the rest it will proceed on momentum alone.

The size of the rockets will depend on the payload to be carried, the fuels used, the efficiency of the motors and the distance to be covered. So many variables are involved it is possible only to make a rough estimate as to the dimensions, but we can get some guidance from the German "V-2" rockets (page 162). These were, of course, simply load-carrying trajectory rockets, designed to transport a payload of one ton to a distance of some 200 miles. The rockets themselves at takeoff weighed 12 tons, of which about two-thirds was fuel.

If these proportions should turn out to be typical, we may assume that about 9 tons of fuel will be needed to transport one ton of payload in a simple trajectory rocket over a distance of 200 miles. The rocket itself will be between 40 and 50 feet in length. It will be a pointed cylinder, some 5 feet in diameter at its widest part. Its motor will have a starting thrust of about 25 tons.

7.

Assuming that rockets of sufficient power and capacity can be developed to make them otherwise practical, a question that often comes up about mail rockets is control. How well could the trajectory be managed to prevent loss of the rocket and its cargo?

An unguided rocket can be expected to exhibit an inaccuracy of at least one per cent of the distance traveled. That is, a 100-

mile rocket, even though properly launched on course, would not be likely to land closer than within one mile of its projected destination. A 500-mile rocket might miss its target by five miles or more; its landing field would have to be at least ten miles across. Vagaries of wind, nozzle imperfections, mishaps in flight or slight miscalculations at the launching would increase the inaccuracy a great deal more. It is obvious that by aim alone we could never hope to produce a trajectory rocket of sufficient accuracy to deliver cargo where and when wanted.

The accuracy can be very considerably increased by the use of internal guiding mechanisms. Theoretically, a rocket could be made to guide itself quite accurately without external aid, by the use of complex accelerometer devices capable of detecting any deviation from the pre-set course. In practice, such equipment would have to be so delicate and complicated it is doubtful that it could be developed.

The gyroscope, however, offers a simple and sturdy approach to an internal control mechanism which could readily control some of the main elements of the flight. With its axis laid in the direction of the flight, it could quickly detect any lateral deviations from the course, and transmit corrective impulses through suitable servo-mechanisms to vanes, movable motor nozzles or other guiding equipment.

Even with the best gyro-controls, however, the shot cannot be fully accurate. The gyro itself will always contain certain imperfections that will introduce deviations. Moreover, it will be unable to do anything about detecting or correcting drift, such as might be introduced by cross-wind currents. And a gyro could not control the range of the rocket, which is principally established by the rocket's velocity at the fuel cutoff point.

The final correction of all trajectory rocket flights will probably have to be managed from the outside, and many strange and perhaps impractical ideas have been suggested to provide it.

In one scheme the nose of the rocket would be equipped with photocells, so balanced through an electrical circuit that they could be made to guide the rocket by keeping its nose pointed at some certain bright object in the heavens, such as a fixed star. This idea has been much discussed by rocket enthusiasts, and it has a certain poetical attractiveness. But a fixed star is actually such an indistinct target the accuracy could not be very great.

A variation of the photocell idea is the suggestion that the nose of the rocket be equipped with a television transmitter capable of sending an image back continuously to the launching station. By thus taking a fix on landmarks or skymarks, it is proposed that a distant operator could steer by seeing what the rocket "sees," correcting any deviations by means of shortwave radio.

By all odds, however, the most promising scheme is simply radio-control, supplied automatically by two cone-shaped short-wave beams, one sent from the launching station, the other from the receiving site. So long as the rocket remains within the beams, it could go its way unmolested, guided only by internal gyro-control. But if it should wander near the edges of the beam, or out of them, the automatic radio control device would immediately make the necessary corrections, bringing the projectile back on course by means of movable vanes, fins or brief bursts of rocket power.

Toward the end of the trajectory, when the increasing density of the air might introduce new deviations, the rocket could put out wings, concealed in its body during the takeoff and flight, but now serving both to slow the rocket's descent and act as an auxiliary steering device. Such wings could be controlled from the landing site by an operator in visual as well as radio contact with the rocket. The wings, transforming the projectile into a glider, would also increase the flight distance to a not inconsiderable extent.

It should be kept in mind that during most of its flight a load-rocket will be a very light affair; its shell virtually empty. If its starting weight is 30,000 pounds, its landing weight, cargo and all, will be only about 10,000 pounds. Wings which could not fly it at all at the start will be quite adequate to guide and land such an empty projectile at the termination.

Chapter XV

Faster than the Sun

1.

A LITTLE over a century ago, when George Stephenson proposed in a magazine article to construct a locomotive with twice the speed of a mail coach, a critic declared: "It may just as well be expected that the inhabitants of Woolwich will consent to ride on a Congreve war rocket as trust their lives to such a machine."

Stephenson accordingly named his locomotive the "Rocket." It hauled passengers in a carriage at the frightful speed of twenty-four miles an hour.

Since that day there has been a steady increase in the speed at which passengers have been willing—and anxious—to travel. So popular are 100-mile an hour railway streamliners it is virtually impossible to get reservations on one of them. Airports swarm with people eager to fly at speeds of 200 miles an hour. There seems no reason to doubt that passengers will be available for flight at almost any speed, provided the risk is comparatively small and the economic requirements are not beyond reach.

Whether the age of rocket power will include giant passenger-carrying versions of the mail rocket must depend on many developments, but there is no theoretical reason why it could not do so.

Up to this writing no human being has ever been a passenger in a true rocket, though numerous animals from mice to roosters have been shot by rocket and returned none the worse for it.

Some years ago, in 1933, a story came out of Germany that a man-carrying rocket had transported to the considerable altitude of six miles one Otto Fischer of Barmbeck, near Hamburg. The rocket in which this flight was supposed to have been made was attributed to Fischer and his brother Bruno, but rocket experimenters in Germany were unable to identify or locate either of the Fischer brothers or learn anything about their experiments.

The whole story was undoubtedly a hoax, possibly based on some projected but unsuccessful experiments then in progress at Magdeburg.

The probabilities are that passengers will not be traveling in rockets until after these projectiles have been fully developed for carrying mail and express. Some daring venturer may then undertake to ride a large mail rocket, with such precautions for his comfort and safety as he may be able to manage.

The minimum requirement for a human passenger would be an enclosed cell supplied with air at about sea-level pressure, continually enriched with oxygen and purified of excess carbon dioxide. The passenger would also need some shock-absorbing equipment, in case of a hard landing. If the takeoff acceleration were high, he would need to lie down in a spring-mounted hammock or cot.

He would have to depend entirely on the automatic steering gear of the rocket; it would be out of the question for him to have any control over these functions. At the necessary velocities of the trajectory rocket, a human pilot's reflexes would be too slow and erratic.

In the first flight it would probably not even be possible for the passenger to see where he was going. His quarters would be cramped; provision for windows and the like would add excess weight.

Even if there were windows, the rocket traveler would be able to see little. On the upward part of the trip, he would perhaps catch a vague glimpse of the ground, rapidly receding from him. Clouds and mists of the upper stratosphere would soon obscure the familiar features of the earth. In the stratosphere the world would be completely buried in haze; the glare of the sun would hurt his eyes.

Almost before he could be expected to adjust himself to such rapid changes, he would be on the downward journey again, approaching his destination so rapidly he could catch only a hasty glimpse before the slowing rocket, coming in on its wings and vanes, would be seeking the landing place.

The first passenger will spend a cramped and terrifying few minutes far above the earth. He will have nothing whatever to say about the course of the flight or the ending of it. And very likely he will be glad enough when it is over.

2.

Transport of passengers by rocket is clearly only a special extension of the problem of the mail rocket.

But human freight is somewhat more delicate than other kinds of cargo. A good deal more attention will have to be paid to the rates of acceleration at the launching and landing. The pressure-cabin will need to be something more than a glorified payload compartment. The comfort of the pasengers will need close consideration. Since these rocket trips will be by no means cheap, some luxury in appointments is also indicated.

None of these matters is such as to keep engineers from ultimately producing rocket passenger transportation—if the difficulties in the way of developing mail rockets can be solved. As in mail rockets, the distance that can be flown will depend primarily on the jet velocity of the motors, whereas the amount of payload will be simply a matter of size and skillful construction. If a ton of mail can be transported by rocket, a suitable rocket can also transport, over the same distance, a ton of passengers.

It is even possible to offer some conjecture as to the size of the rocket that would be needed. We will first have to make a few assumptions as to the power of the motors, the ability of the designers to create a sufficiently light and strong rocket structure, and the like. None of these assumptions requires us to accept an impossibility—so far as we now know.

We begin by assuming that the motor will have a jet velocity of 8,000 feet per second or better; this velocity will readily enable us to design a single-step rocket that could fly, let us say, from New York to Pittsburgh—400 miles. This jet velocity is at least 1,500 feet per second better than that of standard rocket motors now in use, but it represents only half the theoretical velocity of such propellants as acetylene and liquid oxygen, and it has been exceeded in the laboratory. It is therefore quite within the limits of what can probably be attained by the time we are ready for rockets of this size.

The only other assumption we need is this: that we can design a rocket capable of actual fabrication, with a payload-structure-fuel ratio of 1 to 2 to 6. For every ton of payload in such a rocket, there would be allowed two tons of structure and six tons of fuel. Ready to fly, the rocket would weigh nine tons. At the

end of the firing period, it would weigh three tons. And when the passengers and pilot disembark at destination, the empty carcass will weigh only two tons or a little over.

If such a rocket could be built, preserving the proportions outlined and weighing nine tons at the start, it could fly 400 miles or thereabouts (less the amount subtracted by the resistance of the air), carrying one ton of payload.

This one ton of payload, however, could not consist wholly of passengers: it must also include the weight of the pressure-cabin, the air-conditioning equipment, the seats or hammocks, the safety devices inside the cabin, the passenger's baggage, little touches of luxury such as pillows, padding, drinking water and the like. It would also include the weight of the pilot and his equipment.

From this we conclude that only about four passengers and the pilot could be carried. Permitting them an allowance of 200 pounds each for persons and baggage, only 1,000 pounds would remain for all the rest of the equipment of the passenger compartment, a slender margin, but possibly it could be done.

3.

We have raised the question of the cost of the trip, and now we can look at that a little more closely. A concrete fact stands out; 6 tons of fuel will be required in such a rocket to transport four passengers from New York to Pittsburgh. The fuel will consist of liquid oxygen and acetylene or gasoline. Twenty cents a gallon—roughly 2½ cents a pound—would be a conservative but reasonable estimate of its cost. This brings the fuel bill to $300 per trip, or $75 for each passenger.

It would be foolish to try to guess what the rocket itself would cost, or how many trips it could make daily (the actual flight time, of course, would be about seven minutes per trip). Or what costs would be involved in maintenance, rocket-port operation, ticket sales, administration, overhead, taxes, allowance for depreciation, dividends to stockholders, obsolescence, insurance, provision for damage suits, and all the other necessary costs and charges that go to make up a large-scale transportation budget. It seems safe to guess that the cost of a ticket from New York to Pittsburgh by passenger rocket, on the basis of the craft we have before us, would come to about $300 or $400 at the least.

Since the rail trip, with Pullman accommodations, costs only $20.77 and an airplane ticket including transportation to and from the airports comes to only $25.01, this is rather a steep price to pay for saving, at the most, two hours in travel time.[1]

We do not need to assume, however, that this matter of cost eliminates the passenger rocket. The 9-ton rocket in all probability would be a minimum size; about like trying to haul passengers profitably in a two-passenger airplane. If the size were doubled, the number of passengers to share the cost could perhaps be increased by somewhat more than twice, since the problem of hauling passengers involves considerations of bulk as well as weight. In an 18-ton rocket, we might be able to transport nine passengers; in a 36-ton rocket, possibly 20—bringing the fuel expenditure per passenger down to just a little over a ton.

In the age of rocket power, other fast jet-driven craft will of course be in operation too. There may be gliders carrying passengers at 400 to 500 miles an hour powered perhaps by athodyds. There will be stratosphere aircraft driven by turbo-jet engines, possibly augmented by duct engines, traveling as fast as 600 to 700 miles an hour. There may be huge turbo-jet stratoplanes flying at altitudes of 10 to 12 miles, boosted through the higher portions of their flight by auxiliary rocket motors permitting them to go as fast as 1,500 miles an hour.

However, the passenger-carrying rocket would present a form of speed competition impossible for others to reach. As against the dimly possible 1,500 miles an hour top speed of the rocket-boosted turbo-jet airplane, true rocket ships for long-distance flying would be able to make—indeed, *would have to make*—velocities as high as 7,000 to 12,000 feet a second at the end of powered flight—or more than 5,000 miles an hour.

4.

Can human beings withstand such enormous velocities? Is it sane to think that people will subject themselves to such strains, just to get rapidly from one point to another?

[1] Standard passenger airlines make the journey between New York and Pittsburgh in two and a half hours with one stop at Reading; and in two hours and ten minutes nonstop.

When railroads were first proposed, one of the objections raised against them was the menace to human life of travel at fifteen miles an hour. When speeds of one hundred miles an hour were promised by the early airplanes, it was frequently asserted that human beings could not stand such velocities.

The human body, however, has proved to be a pretty tough article. As passengers on the space-ship Earth we are at this moment riding around the sun at a velocity of almost nineteen miles a second—yet we are not even aware of it. It is not velocity that affects the human body; we could probably travel at literally any speed. What makes a difference is the *change in rate* of speed, either increase or decrease; in short, acceleration.

The upward flight of a rocket at the beginning of its journey is, of course, an accelerated motion, and in some types of rockets the acceleration rate may be very high: ten to fifteen times gravity.

Two types of inquiry come to mind therefore in considering whether it will be possible for human passengers to ride in rocket ships: (1) what is the maximum acceleration that human beings can stand? and (2) what starting acceleration would be required by a practical long-distance passenger rocket?

The ability of human beings to tolerate acceleration has been the subject of some research, since this is a factor in establishing the speed at which a dive-bomber can attack and pull out safely. It is generally accepted that a healthy, normal young man can stand six to seven gravity acceleration (224 feet per second each second) without serious effect, though many men temporarily "black out" at accelerations above this point, owing to reduced blood pressure in the brain. Blacking out, even at nine gravity or higher, can usually be prevented by a prone position relative to the force of acceleration. There have also been developed special "g-suits" which help to relieve the situation.

Some years ago, when many rocket theorists were intrigued with the idea of interplanetary travel, Thomas W. Norton, a member of the American Rocket Society, gathered together some data for *Astronautics*, indicating what a human being might be able to withstand in the way of extreme acceleration for short periods. He quoted an experiment performed in Germany, in which an aviator was rotated on a large centrifuge. He safely withstood an acceleration of 51.5 meters per second, which

figures out to between four and five times gravity. What is more, he withstood it for upward of five minutes.

Mr. Norton also discovered a case in which a fireman jumped from a building 82 feet high into a net which sank only three and a half feet. While the acceleration to which he was subjected was only momentary, it nevertheless was twenty-five times gravity.

With the aid of another young scientist at the Rockefeller Institute, in New York, Mr. Norton performed some acceleration experiments on small animals. In one test a normal white mouse was rotated at 600 revolutions per minute in a centrifuge, which created an acceleration of 2,629 feet per second per second, or more than 82 times gravity. The pressure was kept up for more than a minute. When taken from the centrifuge, the mouse appeared dizzy for a few minutes, and then rapidly became quite normal.

Apparently the principal physical effect of acceleration on a living creature, at least up to the point where blood vessels are ruptured or vital organs damaged, is only a momentary derangement of the circulation, causing faintness or giddiness.

The subjective effect, however, is an acute sensation of greatly increased weight. This may be quite distressing, and the average civilian passenger will not relish being subject to acceleration much beyond three or four times gravity. If he normally weighs 150 pounds, a passenger subjected to an acceleration of three gravity will feel as though his weight had been increased to 450 pounds. This is quite a load, but he will be able to tolerate it if he is lying down, and is required to do no physical work. At four gravity, his weight would seem to be 600 pounds, at five gravity, 750 pounds. These pressures would probably be insupportable to most people; it would be possible to breathe only with great effort.

From all this we may safely conclude that the maximum practical average acceleration permissible to a passenger-carrying rocket would be about three or four times gravity, or 96 to 128 feet per second per second.

Now, it happens that this figure also works out well in the design of large rockets intended to start from the lower atmosphere. For while it is theoretically most advantageous in rocket operation to discharge all of the propellants in the shortest possible time, it is practical to do it only in the vacuum of space, or

in the very thin upper air. If the rocket is intended to leave from the surface of the earth, we must make some compromises with air resistance. Interestingly enough, the calculations come out to the effect that a long-range rocket, everything considered, should have an average acceleration of about three times gravity.

We may therefore accept it as a safe guess that not only could passenger rockets be manufactured that would transport human beings over long distances at better than mile-a-second speeds; but also that the passengers would be able, under most circumstances, to stand the acceleration involved.

5.

Of course acceleration is not the whole story. The psychological difficulties encountered in rocket flight might well be less easy for the passengers to take than the physical ones.

The rocket is accelerated for only a brief part of its journey—the first minute or two will be quite enough, at 3g, to provide the velocity needed. The fuel having by that time been expended, the motors will cease operation. Instantly the passengers will pass over from a condition of accelerated flight, in which their normal weight will appear to have been multiplied three or more times, to a condition the physicists call "free fall," *in which they will seem to weigh nothing at all.*

Absolute weightlessness is a condition to which no human being has actually been subjected, and consequently we have no way of knowing how the human body will respond to it. Possibly there will be no unpleasant physical effects, but there are bound to be psychological ones, the extent of which we cannot now judge.

For the state of weightlessness is approached in human experience only in falling. There may accompany this experience in flight an emotion of intense terror. Most of us are mortally afraid of falling. It is fear acquired early in life and it never leaves us. Yet two or three minutes after taking off from the rocket port of the speculative future, our passengers will be plunged into it. What is more, the experience will endure for a relatively long period of time, depending on the distance of the flight.

These sensations accompanying free fall will be matched by

some other queer experiences. Since everything in the rocket ship is in free fall with it, none of the objects riding with the passenger will appear to have weight either. Our lives are so conditioned to things as they normally behave on earth; with gravity holding everything in its place: causing liquids to flow downhill, balls to roll from higher levels to lower, and all solids to stay in place because of their weight; that our passengers will be astonished indeed.

Assuming they are hungry, and food is available, they will find it out of the question to eat solids from open plates, or move them to the mouth in ordinary spoons or forks. When pushed or disturbed in any way, food will simply float away in the direction of the push. Unless pierced by the tines of the fork, foods will not hesitate at the mouth, but will waft gently upward and land against the ceiling. If nourishment is to be taken at all during the journey, it will have to be served in collapsible tubes, like toothpaste, and squirted directly into the mouth.

Liquid in open containers will be impossible to drink. A glassful of water would float up out of the glass in a round globule. If touched, its surface tension would cause it to crawl wetly over the person or object contacting it, like some squashy and sentient ameba. Liquids will have to be served from collapsible containers like hot water bottles or the wineskins of the Spaniards.

The passengers will have to be strapped to bunks or hammocks. If they attempt to walk about during the period of free fall, they will very likely bump their heads against the ceiling. For the pilot there will have to be toe-straps in the floor to engage his feet; or possibly he can be supplied with steel-soled shoes, magnetized sufficiently to cling to the steel floor of the cabin.

6.

At least one more experience will be facing the passengers before their journey is done. What goes up must come down. If the projectile is carrying human freight, it cannot come down as rapidly, or with as much of a bump, as it could if the payload were merely mail or express.

To match the acceleration of the upward flight, the rocket ship will now need to decelerate. A common suggestion for handling this is to restart the motors, this time in the direction

of flight. This would require the expenditure of more fuel, a supply of which would have to be retained in the tanks.

Here we run into real difficulties. It would not take anything like as much fuel to stop the ship as it did to start it, for the rocket burns up a major part of its weight in the first minutes of flight. Nevertheless, if fuel is required to do the entire job, the results are disastrous to our project. In the imaginary rocket ship we have been discussing, the starting weight of the loaded rocket (20 passenger size) was 36 tons. Twenty-four tons of this mass would be required to provide velocity for the trajectory, leaving 12 tons to make up the weight of passengers, construction—and fuel to bring the projectile to a suitably gentle stop.

The fuel-weight ratio for stopping would have to be the same as that for the start. So of this twelve remaining tons, eight would need to be jetted out of the motors in the direction of the flight, in order to reduce the speed of the final mass to zero. The final weight, therefore, would be four tons. But *four tons* was the total weight of our projected payload alone; so we are confronted with the quite impossible task of constructing the rest of the rocket out of nothing at all!

But why not make the atmosphere do the stopping for us—adding a few dozen miles or so to the length of the flight in the bargain? This could be done if the rocket were equipped with a set of retractable wings and tail surfaces, folded into its body during the beginning and middle phases of the flight, and now opened out as the projectile falls toward the earth. In the lower stratosphere the density of the air, at the high speed of the falling rocket, should be enough to make the wings take hold. The rocket is mostly empty now, and will itself provide lifting surface when the wings give control.

Here too is where the pilot, who had nothing to do earlier but reassure the passengers, begins to earn the extra fuel his passage has cost. He now becomes the captain of a 12-ton glider. It is his responsibility to nurse the last yards of distance out of the glide and bring the ship as gently as an angel to its berth at the waiting rocket port.

7.

You are entitled to believe in the possibility of the passenger rocket ship or not, as you please. But you cannot dismiss it as an impossibility. If development follows the sequence rocket engi-

neers expect: from thrustor to sounding rocket to rocket mail and express, there is no logic in concluding that this final step cannot be taken, too.

The passenger rocket certainly offers some fascinating possibilities. A hurried businessman, for example, would be able to take off from Paris for New York, or from New York to Los Angeles, and fly faster than the sun. As he speeds forward in his high, celestial trajectory, the day will become younger as he moves: he will actually save time by travel.

Chapter XVI

Journeys to the Moon?

1.

WHENEVER rockets are discussed, someone is almost certain to ask that most difficult of all questions: "Would it be really possible to shoot to the moon?" Every man who deals with rockets has by this time developed a favorite reply—but it still remains the greatest unanswered question of them all.

There is, of course, some limit beyond which the rocket cannot be pushed. Nobody knows today what that limit may be.

We have seen how the intellectual escapists of Europe, in the bitter postwar years of the early twenties, wrote more than twenty-seven books on the subject of flight in space, each feeding on the other; piling higher the mountain of theory, surmise and hope.

The first book in English to deal with rockets, aside from the technical report of Dr. Goddard in 1919, was also devoted to the subject of interplanetary flight. It was a volume by David Lasser, called *The Conquest of Space*; now out of print.

Mr. Lasser, writing in 1931, explored with enthusiasm the thesis that the rocket, with its ability to fly in airless space and its promise of tremendous velocities and power, at last offers a practical means of leaving the earth. In semifictional fashion he postulated a passenger-carrying moon-rocket, the "Terra," 150 feet high with a starting weight of 10,000 tons; constructed in the fashion of a step-rocket with three steps. Terra was to cost "more than $100,000,000" and was scheduled to make the trip from the earth to the moon in forty-eight hours.

Such projects for reaching other worlds, of course, go back many years. Literary proposals for flying to the moon, planets, and stars are numerous.

In 1705 Daniel Defoe, creator of *Robinson Crusoe*, published a book about space traveling entitled *The Consolidator, or Memoirs of Sundry Transactions from the World in Moon.*

He was necessarily vague about the mechanics of his space ship, conceiving it to be formed in the shape of a chariot "on the backs of two vast bodies extended by wings which spread about 50 years in breadth." The wings were made "of feathers so nicely put together that no air could pass; and the bodies were made of Lunar earth which could bear the fire."

Defoe, however, provided one little touch which may have considerable appeal to future interplanetary travelers, especially if they happen to be liable to space sickness. "The person being placed in this air chariot," he wrote, "drinks a certain dozing draught that throws him into a gentle slumber, and dreaming all the way never awakens until he comes to his journey's end."

Antedating Defoe by more than sixty years, John Wilkins, later Bishop of Chester and a distant ancestor of Sir Hubert Wilkins, the polar explorer, wrote in 1640 a most serious book, *The Discovery of a New World*, in which he undertook to prove that the moon is a world like our own, and that man would someday find a way to visit it.

Bishop Wilkins argued the idea that the atmosphere, though thinned by distance, extends all the way from the earth to the moon; also that it will ultimately be possible for men to fly there, either on wings attached to their bodies, or by harnessing huge birds "such as the great Ruck in Madagascar, as Marcus Polus, the Venetian mentions."

"The perfecting of such an invention," Bishop Wilkins truly remarked, "would be of such excellent use that it were enough not only to make a man famous, but the age also wherein he lives. For besides the strange discoveries that it might occasion in this other world, it would be also of inconceivable advantage for traveling, above any other conveyance now in use."

Some years earlier, in a fantasy called *Domingo Gonzales*, a similar idea was suggested by Bishop Godwin. He proposed that the "Swans of the Indies" could be taught to carry men by having a machine to divide the weight among them.

A few hundred miles away in France, a well-known novelist was also at work on an interplanetary book in 1640. He was Cyrano de Bergerac, and the book was called *Voyages to the Moon and the Sun*. In this work appears the first literary mention of rockets used for nonterrestrial flight.

In the first part of de Bergerac's story his astronaut experi-

mented with a belt "holding bottles filled with water." The sun was supposed to change the water to dew and draw it up into the heavens, the hero along with it. The plan didn't work very well, even in the book. The astronaut landed not on the moon but in "New Canada." Here he tried a second time, and finally reached the earth's satellite in a boxlike chariot *propelled by rockets.*

De Bergerac thus hit upon the one and only device that even in theory can carry a load of any kind from the earth to the moon or planets. To go there by swan-power, airplane or balloon is of course out of the question. These depend on air, and the air extends only a tiny fraction of the way from the earth to its nearest neighbors in space.

The rocket however offers at least a theoretically possible way to escape from the earth, and thus possibly to reach the moon or planets.

2.

Upon reflection, it will be seen that the problem of space flight is basically only an extension of the already familiar sounding-rocket problem. To shoot five miles high, and to shoot 240,000 miles high, are qualitatively the same thing, though of course enormously different in degree.

In our earlier discussion of sounding rockets we assumed that the force of gravity is constant, as for practical purposes it is when we are dealing with short ranges. When we begin to consider shooting as far as the moon, we must take the peculiarities of gravitation into fuller account.

The well-known "law" of gravitation asserts that all bodies in the universe attract each other in proportion to their masses, and inversely as the square of the distance between them. Thus the earth's attractive force extends to infinity, but it nevertheless decreases with distance—and rather rapidly. At some 4,000 miles above sea level it is only one-fourth as great as at the surface. An object that weighs four pounds at sea level would weigh only one pound at 4,000 miles. At 12,000 miles, the same object would weigh only a quarter of a pound; at 28,000 miles it would weigh one ounce. But *it can never be able to get so far away from the earth that it would weigh nothing.* The attraction extends theoretically to the outermost corners of the universe.

Now the power of gravitation must somehow be overcome before we can reach the moon or a planet—before the sheer distances to be spanned have any significance. It is common experience that, though a ball or other object may be thrown into the air with considerable force, it always returns. The harder it is thrown, the farther up it will fly, but sooner or later the earth brings it back again.

There is a velocity, however, at which such an object, thrown in a direction away from the earth's center, will never return. It will continue to fly outward at constantly diminishing velocity, but will always outrun the power of gravity at that distance to pull it back. The velocity enabling a body to do this, called the parabolic velocity, or the *speed of liberation* from the earth, is just 6.64 miles a second. A body given such an outward speed—7 miles a second for convenience—will forever escape our planet.[1] It will continue to fly away until it encounters another body with a gravitational field sufficiently powerful to draw it in.

If the object arrives at the orbit of the moon at a time when the moon is also at that point, it will successfully make the lunar journey. If it misses the moon, it will be drawn in toward the sun, but may nevertheless reach safe haven on Venus, our sunward neighbor some 25 million miles away, provided Venus is in exactly the right place in her orbit to meet the falling projectile.

If the object is to be projected *toward Mars*, however, the speed of seven miles a second will not enable it to reach that planet. For Mars is in the direction opposite the sun, and to reach that planet it must move also against the sun's gravitational field, which is more powerful than that of the earth. At the distance of the earth, the speed of liberation from the sun is 26.2 miles a second. It would be necessary, therefore, for a body to leave the earth's vicinity with at least that velocity before it could reach the orbit of Mars, 35 million miles away.

3.

We now begin to see the outlines of the interplanetary problem. We shall have to build a rocket capable of shooting away

[1] This velocity, of course, must be reached outside the earth's atmosphere, or in its highest levels. Otherwise air resistance and friction would cooperate with gravity to slow down the shot.

from the earth at seven miles a second. This speed would drive the rocket forever into space, and should be ample to carry it to the moon.

Obviously unless it were a very large rocket it would be ill-suited for human passage. Moreover, it might be impractical, if not inhuman, to send a living voyager on a journey of such hazard until it was certain that the rocket would be a success. At the first shot anyhow, it would be best to dispatch some significant but non-living cargo; preferably something that could signal back to earth that the moon had been hit.

Along this line was the idea suggested by Goddard in his 1919 report. It was his proposal that a packet of flash powder be sent to the moon and discharged at the surface, indicating by its brilliant light that the rocket had reached its mark. He made some ingenious experiments to determine the amount of powder needed, and came to the conclusion that as minute a quantity as 2.67 pounds would produce a flash strong enough to be "just visible" from the earth in a telescope of one-foot aperture. If the moon investigators wished to be extra generous, a "strikingly visible" flash could be produced with 13.82 pounds.

These quantities seem incredibly small. Conditions would need to be exactly right for a successful outcome of the experiment. The powder would have to be ignited on the dark surface of the moon when in conjunction—that is, a "new moon." Further, the terrestrial weather would have to be clear and the seeing good. Astronomers would have to be looking at just the right spot very intently, and unless someone were lucky enough to get a photograph at the proper instant, there would never be any certainty afterward whether they had really seen the light of the moon-rocket's charge, or were just victims of some temporary aberration of the eye. There would, of course, be no second look. The flash would go off once and be gone forever.

In view of this difficulty, many other suggestions have been offered. Several experimenters have proposed that a charge of high explosive be sent instead of the flash powder. It would blow a crater in the surface of the moon such as might be continually visible; a permanent evidence of man's first success in contacting his neighbor in the heavens. Some distinctive material, such as lampblack, plaster of Paris, a fluorescent or phosphorescent powder or one of the brilliant blue, green or red dyes, could be

mixed with the explosive, to be splashed far and wide around the crater, making it easier to locate.

More ambitious suggestions have also been proposed. For example, a giant radiosonde, capable of operating throughout the flight, sending back to earth a continuous record of conditions in space.

This apparatus would have to be specially developed, but would not necessarily be particularly heavy. Mr. Wyld, who has been giving it some study, estimates that if the methods of "micro-instrumentation" and ultra-short waves are used, with directional receiving and transmitting antennae, relatively little power would be needed. He believes a space-operating radiosonde might be constructed which would not weigh over 50 to 100 pounds. In this estimate Dr. J. A. Hutcheson, associate director of the Westinghouse Research Laboratories, concurs.

The radiosonde would almost certainly be destroyed upon landing. For unless extra fuel were carried along to slow the arrival, the rocket would strike the surface of the moon with a velocity at or slightly above the moon's speed of liberation—about a mile and a half a second.

Perhaps, therefore, it might be well to combine the radiosonde with Goddard's suggestion of flash powder, or the explosive and lampblack idea. Almost all of the calculations indicate that very small quantities of such materials would be adequate: between ten and fifteen pounds altogether.

We might thus arrive at a burden for our first "target rocket" of something like 100 pounds or less—a payload presumably capable of giving us a record of the conditions of the flight, and also a signal upon arrival: either a flash of light or a permanent new crater on the moon lightly dusted with some high-visibility material.

With such a small payload, the target rocket itself could be relatively quite small, and the project seems promising.

4.

Let us now consider what would be required to attain the speed of liberation with a small rocket of this sort, carrying a payload of only 100 pounds.

Seven miles a second is just under 37,000 feet per second. If

we had a motor capable of delivering a jet velocity of that amount, the problem would be simple. We could simply construct a moon-rocket on the familiar 2 to 1 fuel-weight ratio. The rocket would, on consuming its full charge of fuel, have attained the speed of its own jet, and presto, would be launched into space.

But at present there is no known way to construct a motor that delivers 37,000 feet per second jet velocity. In fact there is no chemical fuel that can produce a jet even half so fast, except possibly the as yet unobtainable liquefied monatomic hydrogen. We can count definitely on a jet velocity of between 6,000 and 7,000 feet per second only. If we are to be limited to velocities of this order, we must find some way of building a rocket that will push itself to a speed about six times the velocity of its own jet.

Theoretically we could do it. A rocket can fly at any velocity, and it certainly can exceed its own jet speed if there is fuel enough to continue combustion to that point. But a simple calculation based on the theory of mass ratios shows that a rocket able to give itself a speed six times its own jet velocity would have to be constructed on a fuel-weight ratio of about 404 to 1; that is, out of every 405 pounds of rocket at the start of the flight, 404 pounds would have to be fuel. The construction of such a rocket is of course out of the question, even on paper.

What about a step-rocket, then?

Assuming that we are going to try it with our reliable motor of 6,000 to 7,000 feet per second jet velocity, we will need at least six steps to do the job. We may postulate that each step, carrying all the remaining steps as payload, will add to the velocity of the rocket the speed of its own jet. If the jet speed of the motor is 6,200 feet per second, six steps will provide a total velocity of 37,000 feet per second—the escape velocity—for the final fragment of the projectile carrying our radiosonde and flash powder.

It will readily be seen that the total starting weight of such a multiple rocket will mount up pretty fast. If the final step—the one intended to reach the moon—contains 100 pounds of payload, 200 pounds of structure, and 600 pounds of fuel—a reasonable proportion—this little section alone will weigh 900 pounds.

But the smallest step is only the payload of the next bigger one. So, preserving the same proportions, we have for Step 2:

900 pounds of payload, 1,800 pounds of structure, and 5,400 pounds of fuel: a total weight so far of 8,100 pounds.

At this rate *Step 3* will weigh 72,900 pounds or nearly 36½ *tons*. And we still are only beginning. The total six-step rocket, to carry 100 pounds of payload to the moon, will weigh at starting 26,566 tons!

Now perhaps it will be a mistake to declare it utterly impossible to build such a rocket. Given time, money and desire enough, possibly it could be done. But it would certainly be a magnificently expensive project. The rocket would be two and a half times as heavy as Mr. Lasser's imagined passenger-carrying Terra—and no doubt a lot taller and more impressive. Of course it would carry no passengers at all—only 100 pounds of radiosonde, high explosive and colored powder.

5.

At this point we could simply declare that the space-rocket problem will never be solved. Indeed, it surely cannot be, if we are forced to tackle it with limitations in jet velocity of the order of 6,000 to 7,000 feet per second.

When we begin to assume higher jet velocities, though, things begin to look a bit different. We must still calculate in tons of starting weight for every pound of payload projected into space, but at about 9,100 feet per second jet velocity—a figure probably attainable in the not-too-distant future, we could shoot 100 pounds of payload to the moon with a four-step rocket, which would weigh at launching only 325 tons.

If we could push the jet velocity up to a little over 12,000 feet per second—which, of course, represents about 85 per cent of the energy theoretically contained in liquid oxygen and gasoline—we could shoot 100 pounds of payload to the moon with a *three*-step rocket, weighing less than 37 tons: a total weight only about three times that of the German "V-2" rockets.

What about sending human explorers? Well, in theory of course that could be done too, just as well as sending high explosives or radiosondes. But the trouble with people is that they weigh a great deal, and so do the impedimenta that go with them: pressure-cells, oxygen, water, food, scientific equipment and the like.

People would probably want to come back too; something for which we do not have to provide in the target rocket.

To bring them back would take extra fuel—at least an extra step. This step would permit the human astronauts to conserve the fuel of their last little portion of the rocket, the final step, for escape from the moon's gravitational field and the return to earth.

But that last step, plus the weight of a group of exploring scientists bound for the moon, will complicate our problem very considerably. Let us assume that the scientists and their equipment, and the things needed to assure them reasonable protection and comfort on the trip, will weigh five tons. This would be the payload for our smallest rocket step: the one destined to land on the moon.

The smallest step then would weigh a total of 45 tons, with fuel. We are still preserving our 1 to 2 to 6 ratio and likewise still assuming a 12,000 foot-per-second motor.

The second step, of which the first would be payload, would weigh 504 tons.

The third step would weigh 3,645 tons.

The final step, necessary to permit a return, would bring the total weight of this moonbound spaceship to 37,805 tons!

To build such a rocket would present engineering problems of formidable complexity. Aside from the other problems of such a four-step monster, consider only the matter of the power plant. To launch the craft with a practical acceleration of 3 gravity would require a motor capable of providing a starting thrust of nearly 152,000 tons. The nozzle throat of such a motor, if operated at the pressures used in the smaller motors of today, would have to be more than 24 feet in diameter, and the mouth more than 50 feet. It would consume fuel, at the start, at the rate of more than 400 tons a second.

6.

These are, of course, no small matters to contemplate. And as has perhaps been too-adequately pointed out already, all this conjecture is itself based on assumed jet velocities nearly twice as high as any that can now be achieved. It is reasonable to think that jet velocities will be increased considerably, but there is

undoubtedly an end somewhere to the amount of improvement that can be attained. Where will the limit be?

At jet velocities of 14,000 or 15,000 feet per second, such as might ultimately be reached with fuels like monatomic hydrogen, the interplanetary problem will be relatively easy. At velocities of 12,000 feet per second space flight will, as we have seen, be barely possible. At lesser velocities it appears so extravagant of fuel and materials as to be quite out of the question.

As a practical matter we do not seem to be much nearer the achievement of space flight now than were Bishop Godwin and his swans, or Defoe and his feathered chariot. There is only this difference: a method is at hand that in theory at least could do the job. The road to its accomplishment is clear in outline—but the details are mighty obscure.

In spite of everything, popular enthusiasm for the moon flight is as great as ever. It is difficult to convince many people, even in these days of war rockets and buzz-bombs, that the principal objective of rocket research is not interplanetary travel.

In my personal files there is an interesting little waiting list of hopeful but overly optimistic folk who have written to ask whether they might volunteer for the first flight to other worlds.

One man has told me he intends to deposit $20,000 in a bank to pay for burial of himself and his wife on the moon, in case they do not live to go there as travelers.

Another discloses that he has tried every thrill available here on earth. He has been a circus performer, riding a white horse off a tower into a tank of water. He has also pedaled a bicycle through a blazing hoop. Moreover, he has been married three times. Only Lunar adventure now has any further appeal for him.

These letters would be only amusing, if it were not for what they disclose about the real wellspring of interplanetary interest. When man is plagued by the cares and harassments of his earthly lot, what seems more pleasant than adventure on the moon?

For myself, I do not know whether rocket power will ever permit fulfillment of these desires. Perhaps it isn't of very much moment, for in the age of rocket power, jet propulsion will find plenty of work to do right here on earth. But if there is to be a trip to the moon, count me in. I'd like to go along too!

Chapter XVII

The Day To Come

1.

Back in 1933 the New York *Sun* published a satirical little editorial entitled "The Age of Rockets":

> The next era may be an age of rockets; the present generation may live to see the sky full of whizzing projectiles. . . . The first daredevil to pilot a rocket from Battery Park to the Rue de la Paix in half an hour will become another Bleriot; after him may come the deluge. New Yorkers will take a stratosphere express to luncheon in London. They will go to theaters in Mexico City or Montreal after dinner. Business men and women will commute in rockets from the wilds of Long Island or New Jersey to Wall Street in less time than they can now telephone across the distance. The rocket stations, local and express, will be in the tips of skyscraper towers. . . .
>
> Ordinary aviation will be a hazardous business in an era of rockets. Show the world that a steel tube with a speed of three miles a second is a workable conveyance and some bright fellow will find a way to make them for the public at $250 or less. There will be no tire trouble, but the rocketors will learn to beware of punctured parachutes. When the stratosphere is crowded with missiles that can outstrip the wind, when rockets leap aloft from the ground or swoop to the roofs of the city, anything as close to earth as an ordinary airplane will find itself in a shower of vertical traffic. A dirigible will have no more chance than a soap bubble in a hailstorm. Traffic problems will be slightly different in the stratosphere from those on the ground; it will be easy enough to keep moving, but what driver of a rocket going a hundred miles a minute will stop on a red light?

This is nice fooling, and it is clear that the anonymous writer had no expectation that the conditions he was describing would ever come to pass. It would be interesting to know what thoughts

go through his mind now, in an age of jet-propelled robot bombs, "V-2" rockets, rocket antiaircraft batteries, airplanes that shoot rockets capable of destroying submarines, and infantrymen whose portable rocket guns can smash a tank.

It is now no longer possible for anyone seriously to doubt that the age of rocket power is at hand; at least that it is just around the corner. And as the all-but-forgotten editorial in the New York *Sun* of 1933 suggests, the age of rocket power will bring with it not only new experiences and new possibilities, but it will be accompanied also by new problems.

President Roosevelt once referred to the period when the United States was a "horse-and-buggy country." In a horse and buggy country, people can think of travel only in terms of three to four miles an hour; their economy is geared to a slow enough pace to be compatible with such slow communications. Their outlook is also likely to be restricted, narrow, provincial, understanding little beyond the small community, a day or two's horse-and-buggy journey in radius, in which most citizens of such a country will spend their lives.

In the twenties and thirties we made the leap from a horse-and-buggy country to an airplane country, a radio communications country. We found the transition both pleasant and painful. It was stimulating, but it produced great changes in our economy; enormous ones in our outlook, our responsibilities, our position in the world.

The second World War continued the process. We became a 350-miles-an-hour country; a transatlantic airplane country; a global power, forced to think in terms not of a few miles or even a few hundreds of miles, but of airline distances between the principal cities of the world, great circle routes, 3,000 horsepower airplane engines and networks of landing fields linking every city and town of the world through the trackless atmosphere.

Now comes rocket power, with the promise of speeds that begin where the airplane must necessarily leave off; altitudes beyond the atmosphere itself; flashing mile-a-second craft that will not even need pilots to get them from one place to another across the face of the shrinking globe.

In the coming age of rocket power, we shall have to rise above

the airplane mentality, just as in a previous period we had to adjust our horse-and-buggy outlook to the age of flight.

2.

Despite all human desire, which appears to be set against the recurrence of conflict and bloodshed, it is not inconceivable that there will be future wars. These periods of violent contest between sections of the human race have been concomitants of history since the earliest times, and will probably continue. We shall be merely foolish if we do not contemplate future warfare in the age of rocket power, and make such provision for it as we can.

Rockets, born in the Mongol wars in China, have played an important part in human conflict throughout their history. In modern war, against armor, airplanes and submarines, the rocket is the weapon of choice and necessity. It will be strange indeed if nations, in time of peace, do not continue to develop their rocket weapons assiduously for wars to come.

In the second World War the airplane and the tank, working for the first time as a co-ordinated team, all but decided the contest against the side which was slower to develop these arms and the proper strategy for their use. In the next war, it will be the airplane and the various applications of rocket power which will decide the struggle. If the blitz of 1940 and 1944 was terrific, it was nevertheless mild by comparison with what will be possible through long-range rocket attack, followed up by rocket-strafing aircraft, bazooka-armed paratroops and rocket-driven demolition bombs.

No defense against such weapons has yet appeared. Probably no defense will be possible, except preparation for prompt and instant retaliation in kind and with greater power, provision of shelters underground for civilian populations, principal manufacturing plants and centers of command and communication.

A country sufficiently armed and ready might be able to reduce its opponents' cities almost immediately to rubble following a declaration of war—or even before any such declaration. An attacked nation's first warning might well be the sight, on the radar of the future, of rocket missiles high in the air, sent by the thousands in a cloudburst of metal and explosives. They could

be timed to arrive before the signal indicating their coming could be flashed to the military and civil authorities of the bombarded country. For long-distance attacks, such unmanned missiles might well follow a trajectory so high as to appear to come, not from the direction of the enemy country at all, but almost from overhead.

It might well be that such rocket weapons would be inaccurate, but to make up for that there would be enough to blanket the target. In modern war, there is little distinction between the battle front and the home front. Distinctions between military targets and nonmilitary ones are also a sort of fiction; for in mechanized warfare factories are military targets, and so are communication systems, supply routes for the armies, mines, feeder plants, powerhouses. Anything that leads to demoralization on the home front, even to bombing civilian houses and the disturbance of civilian workers' sleep, is likely to be interpreted by militarists as a useful contribution to the cause.

We may therefore expect that the next war will be ushered in with rocket weapons, and mainly fought with them. World War II showed us what some of these weapons might be and it suggested others. If there is to be a third World War, we may well expect that the armament of both sides will include high-altitude, long-distance, rocket-propelled demolition bombs, capable of delivering tons of high explosives over a range of hundreds of miles; winged jet-propelled robot bombs possibly capable of crossing the Atlantic as easily as the German robot bombs of 1944 crossed the English Channel; high-altitude trajectory penetration bombs, coming down to their targets at such steep angles and with such force as to be able to pierce the ground and explode with the force of small earthquakes.

There will also be airplane rocket projectiles, as much improved in power and accuracy over present types as the airplane itself was improved between the first and second World Wars. These may be used for battles at long distances between aircraft, possibly at such distances that radar will be employed by the opposing air fleets not only to spy each other out, but to aim their projectiles.

Aircraft rockets will also be developed for more advantageous use against submarines, at longer distances, and will probably be adapted for attack even through water; a kind of combination

aerial and aquatic rocket torpedo capable of accurate motion in either medium, possibly steered toward the submerged submarine by magnetic or electrical detecting devices.

Somewhat similar flying torpedoes, with automatic steering devices, are in the offing for use against aircraft bombers; rocket torpedoes which, by making use of sound-detecting equipment, photocells, or magnetic or electrical detectors, will be able to single out and chase to destruction attacking enemy aircraft no matter what their altitude or speed.

In such a war, no spot on the earth's surface will be safe from potential destruction. The Atlantic and Pacific, which since the days of our continent's discovery have served as broad barriers over which no enemy fleet has attacked us, will be no protection against destruction from the air. It will be foolish to think that we can prevent any of this by forbidding the production or development of rockets in vanquished or suspected countries. There will be an industry in rockets for peacetime use. As in the case of airplanes, it will be easy to conceal war preparations under the guise of manufacturing for peace.

> The flying bomb . . . [wrote Major General J. F. C. Fuller on July 17, 1944, for *Newsweek*], What does it portend? In my opinion it portends as great a revolution in the art of war as those successively effected by the bow and arrow, the musket, the cannon, and the airplane. Possibly greater, for as all these inventions aggravated man's propensity for war, it seems to me not at all improbable that this winged projectile may at length bring him to his senses.

3.

It is easy for us to imagine the destructive uses of rockets. These potentialities have been thoroughly burned into our minds by war.

We have no similar experience with rockets in peace, except as delightful toys for producing spectacular displays at celebrations. We try to imagine what of our many present means of communication or conveyance the rocket will replace, and we can hardly think of any. For the fact is, the rocket will not actually compete with anything we now have. It will create a new place for itself in the economy and life habits of the age of

rocket power, as did the airplane in its own time, and the railroad before it.

Rocket power in its various forms will introduce a new dimension into human life. It will find uses which we cannot now even imagine. In addition, it will also make more useful many of the things with which we are now familiar.

On every important airport of the world, it may be, weather rockets will ascend regularly into the stratosphere, providing pilots with accurate, complete data on the weather at all flight altitudes, under all conditions. Improved three-dimensional weather maps, made possible by the speed and reliability of innumerable weather rockets, may enable meteorologists to forecast weather not only for a few hours ahead, but even for days or weeks. Data as to solar radiation and upper-air conditions, added to by high-altitude sounding rockets, may even enable weathermen to forecast the general trends of rainfall, temperature and the like for seasons at a time, to guide farmers in planting and marketers in planning for the even distribution of foods.

If this seems fantastic, witness the success of Dr. Charles G. Abbot, until his recent retirement secretary of the Smithsonian Institution, in forecasting climate months and years ahead with the aid of local weather records and continuous observations of the variations in solar radiation.

From scanty data, so little as to seem most inadequate for such a complex task, he was able to predict that in a given three-month period the rainfall in the Tennessee Valley would be between 84 and 87 per cent of normal. As subsequently measured during the period he named, the rainfall actually turned out to be 87 per cent of normal. On another occasion, he was able to give the chief of the Weather Bureau in Washington a list of the days in which he predicted that the rainfall would be approximately two-thirds greater than on the other days of the year. The actual rainfall turned out to be almost exactly as Dr. Abbot had predicted: 1.58 times as great, whereas his prediction had been 1.65.

These predictions were based on variations in the sun's radiation as observable at the surface of the earth. When it becomes practical to send sounding rockets regularly to the outer edges of the atmosphere, or at least well above the absorbing lower regions of the air, it will be easier to measure both these and other variations having an effect on the weather and climate.

Even long-time trends such as those which produce cyclical droughts and periods of high rainfall may be determined, or cold periods extending over generations of time, such as brought about the great glacial epochs.

The sounding rocket may enrich our knowledge of the earth's atmospheric envelope itself, and disclose more subtle influences: the effects of its aerial tides, for example; the rising and falling of the electrical layers that affect radio transmission throughout the globe; the curious magnetic storms which originate in the sun and sometimes set up such disturbances in electrical equipment on earth.

The possibilities of mail and express by rocket power, or the new experience of riding jet-driven aircraft at great altitudes and enormous speeds—the effect of such things can be only dimly imagined, but they will surely produce revolutions in human thought and patterns of action as significant as those brought about by the radio, the invention of refrigeration, or the development of aircraft.

4.

It is interesting to speculate on the new jobs and new businesses that may spring up around the industry of rockets and rocket power. Obvious, of course, will be the purely mechanical side: the factories for developing and manufacturing duct engines, thermal-jet engines, thrustor motors for an enormous variety of special uses, rocket motors for sounding rockets, mail rockets, weather rockets and war rockets; the rocket body manufacturers; the congeries of industries that may be needed to create, develop and manufacture the control instruments, the pumps, fuel tanks, weather instruments, sounding instruments and radio control devices of these various types of rockets.

The production of rocket fuels may possibly become a special branch of the chemical industry, as did the production of automobile and aviation fuels. Rocket propellants will undergo rapid development, with many new types coming into common use, as chemists turn their attention to the field.

We shall perhaps have monopropellants which are safe to handle, yet yield tremendous power; liquid-oxygen factories, possibly also turning out liquefied ozone in stable form; plants producing alternative oxidizers such as concentrated hydrogen

peroxide, nitric acid and others now unknown. As liquid-fuel rockets grow larger, there will also have to arise a specialized industry for producing pumps for propellants—pumps which will operate at great extremes of temperature and under the narrow restrictions of weight and movement established by the rocket's requirements.

If all this seems unbelievable and fantastic, remember that the aviation industry in 1900 employed nobody; by 1920 it provided 3,600 jobs. Even then, nobody took it very seriously as an economic factor in our national life. But by 1930 it was employing 15,000; by 1940 the number had grown to nearly 50,000 and by August, 1944, more than 1,800,000 persons were employed in this country alone to meet war's demands for a device that had not even been in existence forty years before. All of these were *new* jobs, created out of demand for a new thing in human experience.

Rockets have created new jobs already. It is true that they are wartime jobs and we cannot be told at the moment how many there are. But it was disclosed by the Navy recently that more than $100,000,000 worth of rockets *each month* were being used by that branch of the service alone. It is a safe guess that the Army and other services were using at least as many more.

What will the peacetime jet-propulsion industries amount to, in the age of rocket power? This can no more be estimated now than can the true dimensions of a rocket capable of carrying passengers across the Atlantic.

There will certainly be something of all this rocket effort surviving. As the rocket-power industry grows, it can be potentially at least as great as the peacetime aviation field. In fact, it will actually be *part* of the aviation industry in some of its phases; the development of jet-driven aircraft may work to increase the usefulness, and therefore, the demand for airplanes themselves.

5.

Fast transportation, jobs, industry—these, however, are not what people really live for, in spite of the fact that most of our waking time is devoted to them. The true purpose and fulfillment of life is to know and understand; to see a fuller concept of the

world and its place in the universe, and our own position in the cosmic scheme.

There is something about rocket power which transcends the bleakly mechanical aspects of the subject, and changes its followers into missionaries. It might be the imaginative possibilities of travel through the upper atmosphere, the enormous speeds that are possible, the sense of freedom from cams, gears, reciprocating parts and other paraphernalia of ordinary engines; the almost poetic simplicity and inevitableness of rocket flight.

Possibly it is the fact that rockets will bring us new knowledge of the realms into which mankind has so far been unable to venture, and thus will stretch our mental horizons and enrich the fields of physics, meteorology, radiation and many another science. Perhaps even, it is the lurking chance—the hope and expectation that will not be stilled—that by rocket power we shall actually someday be able to visit and explore worlds other than our own.

Whatever it may be, those of us who have spent years in the study and development of rockets have acquired an emotion about them which is almost religious.

We somehow feel privileged, as though we had stood in these years at some obscure crossroads in history, and seen the world change. We do not know exactly what we have loosed into the earth, any more than Gutenberg with his movable types, or DeForest with his radio tube. But we feel in our souls that it is magnificent and wonderful, and that the human race will be richer for it in time to come.

New speeds, new possibilities, new horizons—both for the human body and the human mind. These are the promises of the age of rocket power—an age that is soon to come. Indeed, it may already be here.

Appendix

A Lexicon of Rocket Power

ACCELERATION. The rate of increase of speed of a rocket during powered flight; usually measured in terms of *gravity* (g) or the rate of increase of velocity acquired by a body in free fall at the surface of the earth.

AIRFOIL. A thin, flat streamlined surface used for wings, rudders or flaps.

AIR RESISTANCE. The resistance produced by the atmosphere toward any object moving rapidly through it.

AIR SOUNDING. Measurements of air conditions at high altitudes by a radiosonde or similar equipment.

AIRSTREAM ENGINE. A reaction motor that depends on the atmosphere to support combustion or increase the mass of the jet.

AREA RATIO. The ratio between the mouth area and the throat area of a rocket nozzle.

AXIAL-FLOW COMPRESSOR. A rotary air-compressor using propeller-like blades through which the air flows parallel to the shaft.

AXIS OF THRUST. An imaginary line drawn through the center of the jet of a rocket motor, along which the thrust or reaction of the motor is directed.

BAZOOKA. A small tubular rocket launcher with hand grips, shoulder stock, and sights, used by infantry to fire antitank rockets.

BLAST CHAMBER. The chamber in which the propellant is burned in a rocket motor or jet engine. (Same as *combustion chamber.*)

BOOSTER ROCKET. An auxiliary rocket device with a large thrust and relatively brief firing time, used to bring a rocket or aircraft up to flying speed. (Same as *thrustor.*)

BUMBLE-BOMB. The German jet-propelled robot airplane used in World War II, also known as the robot bomb, the buzz-bomb, etc.

CATAPULT. A device for launching a rocket or airplane with high initial speed.

CENTRIFUGAL COMPRESSOR. A rotary air compressor similar to a centrifugal pump, in which the air is thrown radially outward by vanes on a flat disk.

CENTER OF GRAVITY. The point at which all the mass of any flying body appears to be concentrated.

CERAMIC LINER. A porcelain-like heat-resistant lining for a combustion chamber.

CHAMBER PRESSURE. Pressure shown by a gage connected to the combustion chamber during firing.

CHEMICAL FUEL MOTOR. A true rocket motor, using propellants supplying their own oxygen (as opposed to the airstream engines, which obtain their oxygen from the air).

CHASE-ME-CHARLIE. British slang for a German remote-controlled glider with a rocket booster, used for attacking ships in World War II.

CHUGGING. Irregular combustion due to incorrect mixture or poor chamber design.

CHUTE BOOT. The parachute container of a sounding rocket.

COMBUSTION CHAMBER. An alternate term for blast chamber.

COMPRESSIBILITY BUBBLE. An unsteady type of airflow around an airfoil operating close to the speed of sound, marked by reduced useful life and increased drag, caused by shock waves on the airfoil surface.

CONCENTRIC TANKS. Fuel or propellant tanks nested one within the other, with a common central axis.

CONSTRUCTION WEIGHT. The weight of tanks, motor, pumps, controls, landing gear, etc. of a rocket, exclusive of fuel. (Same as *structural weight.*)

CONTROLLED ROCKET. A rocket which has a guiding mechanism capable of controlling the direction of flight.

COOLANT. Any material used to cool a rocket combustion chamber or nozzle.

DELAYER. A substance mixed with the propellant of a dry-fuel rocket to decrease the rate of combustion.

DIPROPELLANT. A combination of two substances used as a rocket fuel.

DISSOCIATION. Decomposition of the burned gases in a combustion chamber at high temperature, producing a loss of heat energy.

DRAG COEFFICIENT. A factor representing the relative air resistance of a particular shape of airfoil or hull, used in air-drag calculations.

DROP UNIT. A booster rocket which can be jettisoned after exhaustion of its propellants.

DYNAMOMETER. A device for indicating and recording the thrust of a rocket motor during a test, also called a *reaction balance.*

EXTERNAL (OR BALLISTIC) EFFICIENCY. The ratio between the energy usefully employed in propulsion and the kinetic energy developed by the jet. (Same as *mechanical efficiency.*)

ESCAPE VELOCITY. The velocity at which an object would escape the gravitational attraction of a given astronomical body. The escape velocity of the earth is 6.664 miles per second.

FILL-HOLE. The orifice through which liquid fuels are loaded into a rocket's tanks.

FINAL MASS. The mass of a rocket at the end of flight.

FIN-STABILIZED ROCKET. A rocket which does not rotate in flight, but is stabilized by means of fixed fins or vanes.

FINS. Fixed rudders on a rocket to help give it direction.

FIZZ POT. An airplane booster rocket.

FLAPS. Movable rudders, either attached to the fins or placed in the jet of a rocket, to direct the flight.

FLARE. The bell-shaped inner curve of some types of rocket motor nozzles.

FLARE ANGLE. See "Taper."

FLOW METER. A device for measuring the rate of flow of liquids or gases.

FREE FLIGHT. The portion of a rocket's flight which follows the combustion of the fuel or the turning off of the rocket motor.

FREE-FLIGHT ANGLE. The angular direction of a rocket with respect to the earth, at the beginning of free flight.

FREE ROCKET. A rocket which has no guiding or flight control devices other than fixed tail or fin surfaces.

FT/SEC (OR FPS). Feet per second, a term frequently used in connection with measurement of jet velocity.

FUEL. The combustible component of a rocket propellant; though this term is often used also to denote the oxidizer as well.

FUEL-WEIGHT RATIO. The ratio of the weight of a rocket's fuel to that of the empty rocket without fuel. Also called the *fuel-structure ratio*. It is equal to the *mass ratio* minus 1.

FUSEE. A small pyrotechnic squib used for igniting a rocket motor.

g. Symbol for "gravity," the unit of acceleration equal to 32.2 feet per second per second.

GO-GETTER. A control mechanism for large military rockets or robot planes, especially one intended automatically to guide the rocket to its target.

GYROCONTROL. A gyroscopically operated device for guiding a rocket in flight.

HULL. The outer casing of a large rocket projectile.

IDEAL ROCKET. A rocket constructed to such a fuel-weight ratio that it will reach the velocity of its own jet. In a space this ratio would be 1 to 1.72; the larger number referring to the fuel.

IMPULSE. The total output of a jet motor in a given shot; equivalent to average reaction multiplied by time.

IMPULSE-WEIGHT RATIO. The ratio between impulse (reaction multiplied by total firing time) of a jet motor and the total loaded weight, including auxiliaries.

IGNITER. A device for igniting a rocket motor.

INITIAL MASS. The mass of a rocket at the beginning of flight.

INITIAL VELOCITY. Velocity of a rocket at the start of the firing period.

INJECTOR. The inlet device which admits propellants to a rocket motor.

INLET PORTS. The openings or nozzles through which propellants are injected into the rocket motor. (Also called *injection ports.*)

JATO. Apparatus for producing jet-assisted takeoff, or an airplane so equipped.

JAYPEE. A jet engine, or an aircraft driven by jet propulsion.

JET. The stream of gas ejected by a reaction motor.

JET-ASSISTED TAKEOFF. An airplane takeoff accelerated by the use of a thrustor rocket or jato.

JET ENGINE. An airstream engine: a reaction motor equipped to use oxygen of the air as an oxidizer.

JET MOTOR. A self-contained or true rocket motor: a reaction motor supplied with oxygen as one of its propellants, as contrasted with the jet engine, or airstream engine.

JET PRINCIPLE. The operating principle of all forms of rocket power.

JET PROPULSION. Rocket power: propulsion by thrust developed by ejecting a jet of rapidly moving gas or other substance through a nozzle.

KATUSHA. A multiple Russian rocket launcher, operated either from a special mobile truck or from fixed ground emplacements.

LANDING GEAR. Equipment, usually consisting of a parachute and release mechanism, for bringing a rocket gradually to earth after a shot.

LAUNCHER. The aiming device from which a rocket is shot.

LAUNCHING ANGLE. The angle, measured from a horizontal plane, at which a rocket is inclined at launching.

LAUNCHING RACK. A fixed rocket launcher.

LAUNCHING RAILS. A rocket-launching device, usually attached to an airplane.

L/D RATIO. The ratio of length to diameter of a rocket motor combustion chamber.

LIQUID-FUEL ROCKET. A rocket burning liquid propellants.

LOADED WEIGHT. Weight of a rocket or jet motor apparatus loaded with propellants and ready to fire.

LOX, OR LOXYGEN. Liquid oxygen.

MACH NUMBER. The ratio of the velocity of a rocket or a jet to that of sound in the medium being considered.

MACH WAVES. Nodes or standing waves in a rocket jet, caused by reflection of the jet from the surrounding air.

MASS RATIO. The ratio between the total initial mass of the rocket ready to shoot and the final mass of the empty rocket. Also called *weight ratio.*

MECHANICAL EFFICIENCY. The ratio between the energy usefully employed in propulsion and the kinetic energy developed by the jet. (Same as ballistic or external efficiency.)

METEOROGRAPH. An apparatus for determining or recording atmospheric data.

METERING ORIFICE. A constriction in a liquid feed line for regulating the propellant flow rate.

MONOPROPELLANT. A propellant consisting of a single liquid, which contains both fuel and oxidizer, either combined chemically or in a mixture.

MOTOR. The device that provides thrust for a rocket. (Alternatives—*jet motor*, *rocket motor*, *thrust motor*, *reaction motor*.)

MOTOR HEAD. The upper portion of a rocket motor, usually containing the propellant injection ports and the igniter.

MOUTH. The large end of the expansion nozzle.

MOUTH AREA. The cross-section area of the nozzle mouth.

MULTINOZZLE MOTOR. A rocket motor with more than one nozzle.

Nebelwerfer. A type of German, six-barreled rocket launcher, used originally for launching incendiary and smoke projectiles.

NOZZLE. The orifice and expansion device through which the jet is ejected from a rocket motor.

NOZZLE COEFFICIENT. The amount, experimentally determined, by which the shape of a specific nozzle increases the thrust of the motor.

OXIDIZER. The oxidizing component of a rocket propellant, in general a substance containing or consisting of oxygen available for combustion.

PSF RATIO. The payload-structure-fuel weight ratio.

PARACHUTE RELEASE. An automatic device for ejecting a landing parachute from a rocket.

PARALLEL-TANK ROCKET. A rocket with parallel cylindrical fuel tanks.

PAYLOAD. The useful load carried by the rocket, in addition to its necessary structural weight and fuel.

PAYLOAD-STRUCTURAL-FUEL WEIGHT RATIO. The ratio between the payload, the structural weight and the fuel weight; also called the PSF ratio.

POWERED FLIGHT. The portion of a rocket's flight during which the rocket motor is in operation.

PRESSURE GAS. A gas, usually nitrogen, used to force the propellants of a liquid fuel rocket into the blast chamber during firing.

PRESSURE RATIO. The ratio between chamber pressure and the pressure at the nozzle mouth (or other reference point).

PROPELLANT. The materials used in a rocket motor to produce the driving jet.

PROJECTED AREA. The maximum cross-section of a rocket hull, when viewed head-on.

PROVING STAND. An equipment for testing or "proving" rocket motors. Also *test stand.*

PYROTECHNIC FUEL. A solid propellant which supplies its own oxidizer as part of the mixture, as in the case of gunpowder.

RADIOSONDE. A form of meteorograph transmitting its indications automatically by radio; used in high-altitude air soundings.

REACTION. The recoil or "kick" produced by the jet of a reaction motor, which provides the propulsive force.

REACTION MOTOR. The general term for all types of motors and engines that operate by jet propulsion.

REGENERATIVE MOTOR. A rocket motor equipped with a cooling jacket, through which the fuel flows on its way to the injector, thus carrying the waste heat back into the blast chamber.

REGULATOR. A device for regulating the flow or pressure of gas.

ROCKET. A projectile driven by jet propulsion.

ROCKET FIELD. A proving field or area for rocket experimenting.

ROCKETOR. A rocket engineer or rocket experimenter.

ROCKET POWER. Same as jet propulsion.

ROCKETRY. The field of rocket theory, development, research and experimentation.

RUDDER. A steering device, either attached to fixed fins or placed in the jet of a rocket to direct the flight. (Same as *flap.*)

RUPTURE DISC. A thin disc of special metal used as a safety valve. Also known as *frangible disk.*

SAFETY VALVE. A valve placed in an oxygen or pressure tank to relieve the pressure before it reaches the bursting point of the tank.

SECTIONAL DENSITY. The weight of a rocket divided by its maximum cross-section. Used in estimating air-resistance.

SELF-CONTAINED MOTOR. Same as *chemical-fuel motor* or *true rocket motor.*

SERVOMOTOR. A mechanism to make force act at a distance, proportional to the force impressed upon it, as in gyro-control mechanisms which guide rudders on steered rockets. In particular, pneumatic or hydraulic cylinders used for this purpose.

SHOCK WAVES. Sound waves set up by an object moving at supersonic speeds, causing increased energy losses.

SHOT. A rocket flight.

SPINNER. A winged device like the rotor of an autogyro, used instead of a parachute to bring a rocket gently to earth.

SPIN-STABILIZED ROCKET. A rocket designed to rotate rapidly during flight, thus obtaining stability in the same manner as an artillery shell.

SKIN FRICTION. The drag on an object moving in air caused by the friction of the air on the surface.

SOLID-FUEL ROCKET. A rocket propelled by a solid pyrotechnic propellant; a dry-fuel rocket.

SOLID MOTOR. A nonregenerative liquid-fuel rocket motor.

SOUNDING ROCKET. A high-altitude rocket carrying air-sounding equipment.

STEP-ROCKET. A rocket consisting of several sections or "steps" fired successively, each step being jettisoned when its fuel is exhausted.

SUBSONIC VELOCITY. A velocity less than that of sound.

SUPERSONIC VELOCITY. A velocity greater than that of sound.

TANDEM-TANK ROCKET. A rocket with cylindrical propellant and pressure tanks placed end to end; a single-stick rocket.

TAPER. The angle at which some types of rocket nozzles open out from the throat.

TEST STAND. Same as proving stand.

THERMAL JET ENGINE. A type of airstream engine containing a rotary air compressor to provide air under pressure to sustain combustion.

THERMAL EFFICIENCY. The ratio of the kinetic energy developed by the rocket jet to the thermal energy content of the fuel.

THIRD LAW OF MOTION. Sir Isaac Newton's statement of the principle upon which the reaction motor works: "To every action there is always an equal and contrary reaction; the mutual actions of any two bodies are always equal and oppositely directed."

THROAT. The narrowest part of a rocket nozzle.

THROAT AREA. Cross-sectional area of the narrowest part of the nozzle.

THRUST. The push produced by a jet or rocket motor.

THRUST AUGMENTOR. A funnel-like device for guiding the surrounding air into a rocket jet, thus producing suction which increases the thrust.

TRACKER. A mechanism for observing or controlling a flying rocket from the ground, or the man operating such a device.

TRAJECTORY. The curve which a body, as a missile, describes in moving through space or the atmosphere under the influence of the force of gravity.

TRUE ROCKET MOTOR. A *self-contained*, or *chemical fuel motor*.

TURBO-JET. A thermal jet engine in which the compressor is driven by a gas turbine.

VALVE MAN. The operator who actually fires a liquid-fuel rocket.

vj. The jet velocity of a reaction motor.

WAR HEAD. The explosive section of a large military rocket.

WEIGHT-FUEL RATIO. The ratio between the structural weight and the fuel weight.

WEIGHT RATIO. Same as mass ratio.

WETTED SURFACE. The total external surface of a streamlined hull exposed to air friction.

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